ENCLOSURE A

METEOROLOGY AND AIR COMPLIANCE

Documents Included in this Enclosure

1. **Kewaunee Power Station System Description – Meteorological Data Acquisition System**
2. **Dominion Procedure RP-KW-001-025, Rev. 0 (internal phone number removed)**
3. **Air Pollution Control Operation Permit Renewal, Permit No. 431022790-F20**

KEWAUNEE POWER STATION
DOMINION ENERGY KEWAUNEE, INC.

NMC **KNPP System Description**	Sys No. 63	Rev. 1
Title Meteorological Data Acquisition System (MET)	Date 01/27/03	Page 1 of 9

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Tech Review 6-24-03 Paula K. Anderson	Approved Manager of Engineering

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1.0 Summary

1.1 Overview (See Figures KNP-MET01 and MET02)

The Meteorological (MET) Data Acquisition System Description relates to the system installed in 1982 in response to the Nuclear Regulatory Commission (NRC) criteria for emergency preparedness discussed primarily in NUREG-0654 Appendix 2, Regulatory Guide 1.23 Revision 1, Regulatory Guide 1.97, and NUREG 0737, Supplement 1.

A 60-meter primary tower is located 1200' SSW from the center of Containment, on a bearing of 202°. (See KNPP Location Drawing A-406.) This is instrumented at the 10-meter and 60-meter levels. The primary MET tower provides all the meteorological parameters required to characterize the meteorological environment at the Kewaunee Nuclear Power Plant (KNPP) site. An instrument shed is located at the base of the MET tower. The instrument shed provides local indication of measured parameters as well as a redundant strip recording of essential parameters.

A backup MET tower is located 230' NNE at 24° from the primary tower. This backup MET tower is instrumented at the 10-meter level only and provides backup information to the primary tower. The backup tower is designed to minimize the likelihood of common mode failures to both towers. An instrument shed is located at the base of the backup MET tower. The instrument shed provides local indication of measured parameters as well as a redundant strip recording of essential parameters.

Analog racks located in the Technical Support Center (TSC) Basement, 586' level, provide information display for the integrated Meteorological System. Two side-by-side instrument racks, located in the TSC conference area, provide strip chart/recorder indication of all measured MET System parameters.

The onsite MET System provides a highly reliable, redundant measurement system. Redundancy of the MET System was provided throughout the design although separation criteria required of safeguards systems were not met. An example of redundancy without separation includes separate instrument cables buried in the same underground trench and run in the same cable tray.

Power to the onsite MET tower is provided by a distribution feed from Highway 42 as well an underground feed from Distribution Panel MCC 1-46C, which may be powered from the TSC Diesel Generator. Power to the 10' onsite MET tower is provided by a distribution feed from 3 phase electrical power adjacent to Highway 42.

The analog racks in the TSC also provide signals to the Honeywell 4500C Plant Process Computer (CP) System. MET data is available, via computer terminals, in the Control Room and in the Emergency Offsite Facility (EOF) in the WPS Resources Division Office Building in Green Bay, Wisconsin.

1.2 System Operation versus Plant Modes

Plant Mode	System Support
Startup	The MET System must be operable during plant startup and power operations. These systems are required to assist the plant operators during emergency conditions when a radiological release is either occurring or about to occur.
Normal Power:	
Shutdown:	The MET System is required to be operable during shutdown periods.
Refueling:	The MET System is required to be functional during refueling periods.
Casualty Events:	The MET System is used to analyze environmental conditions such as wind direction, wind speed, and dispersion factors in order to warn personnel that a radiological exposure is occurring and to determine the necessary protective actions to recommend to state governments.
Infrequent Operations	The MET System can be tested during plant operations. The MET System is routinely inspected and verified to be functioning properly.

1.3 Startup

The MET System is normally operational. The MET System may be partially disabled due to loss of power (MCC 1-46C or from Highway 42) for a short time. Restarting the system only requires providing power to the system.

1.4 Shutdown

Portions of the MET System are routinely put out of service for maintenance and calibration. See the appropriate procedure, Section 6.0 of this Chapter, for the required actions to perform maintenance on the sensors/instruments.

1.5 Abnormal

If the Highway 42 power source to the primary MET tower and the backup MET tower is going to be out of service for an extended period, the primary MET tower should be supplied service power from MCC 1-46C by closing the double throw disconnect switch.

1.6 Emergency Plan Implementing Procedures (EPIP)

In the event of a KNPP declared emergency, the EPIPs are implemented and various teams activated if needed. The Environmental Protection Director, the Inplant Radiation Emergency Team, and the Radiological Protection Director must use the EP-ENV procedures to determine potential dose to onsite personnel and to the general public. The following procedures are used to determine Protective Action Recommendations during situations when the health and safety of the public may be jeopardized due to radiological contamination:

EP-ENV-3C	Primary Dose Projection Calculation using the IBM Personal Computer (PC)
EP-ENV-3D	Primary Dose Projection Computer Program
EP-ENV-3G	Manual Dose Projection Calculation using onsite MET data
EP-ENV-3H	Protective Action Recommendations

The EP-ENV-4 Series deals with Environmental Monitoring and Air Sampling.

2.0 Functions

The MET System provides information to Control Room personnel, TSC personnel, and EOF personnel concerning the status of meteorological conditions at the Kewaunee Nuclear Power Plant (KNPP) site. This information can be used to determine the potential hazard of an inadvertent radiological release to the environment and therefore warn government officials of the plume pathway.

The MET system also provides data input to the Plant Process computer. The computer is used to collect and process MET data as required by 10 CFR 50 Appendix I.

3.0 Design Description

3.1 Primary Tower (See Figures KNP-MET01 & MET02)

The Primary Tower consists of two separated components: the 60-meter Instrument Tower and the Instrument Shed.

Vendor (Designer & Installer)	NUS Corporation
MET Equipment Manufacturer	Teledyne Geotech
KNPP Purchase Order	XK-47204

The Primary Tower is a 60-meter Rohn Model 55, instrumented at the 10 meter and 60 meter levels. An electric winch operated instrument elevator system is installed on the tower to allow the 10 meter and 60 meter level instrument booms to be lowered for calibration from the ground level. The elevator runs on tracks mounted on the west face of the tower. The elevator control panel is located at the bottom of the tower. The instrument booms contain ice chippers to ensure free movement on the tracks in winter conditions. The instrument cable has a heated plug and socket, which mate when the boom is in the raised position. When the booms are lowered, a special test jumper is used to connect the instruments and sensors together.

MET parameters measured at the Primary Tower are as follows:

- 60-meter wind speed
- 60-meter wind direction
- 10-meter ambient temperature
- Differential temperature (delta T)
- Aspirator status (air flow through aspirator tube)
- 10-meter sigma theta (sigma theta is a standard deviation for a change in wind direction)
- 10-meter wind speed
- 10-meter wind direction

The instrumentation shed is an 8' x 12' aluminum shelter on a "floating" concrete slab. The shed is provided with baseboard heaters, air conditioning, lights, and local instrumentation readouts. Two separate power distribution boxes are provided to allow the instrumentation power to be segregated from service power. The normal electrical lineup for the 60-meter system is that the instruments are supplied from the plant MCC 1-46C and service power is supplied from the electrical transmission on Highway 42. If power from Highway 42 is lost, tower operation may continue, provided the outside weather conditions do not create hostile operating conditions for the shed instrumentation. If a long-term outage is expected, or weather conditions are severe, the service loads may be manually switched to the plant power feed. A common high/low temperature alarm is provided as a digital input to the plant computer to notify the Control Room Operators of a temperature problem in the 60-meter tower shed.

A digital input to the plant computer indicates when the shed door is open. A sound powered phone extension is provided in the Primary Tower shed to allow communications with the TSC racks when calibrating the MET System.

3.2 Backup Tower

The Backup Tower is a 10-meter wooden pole tower. The Backup Tower provides a minimum set of meteorological parameters for use in the event the Primary Tower instruments are not available.

The meteorological parameters measured at the Backup Tower include the following:

- 10-meter wind speed
- 10-meter wind direction
- 10-meter sigma theta
- 10-meter ambient temperature
- Aspirator status

The Backup Tower system consists of an 8' x 8' aluminum shelter on a "floating" concrete slab. The shed is provided with baseboard heaters, air conditioning, lights, and local instrumentation readouts. Two separate distribution boxes are provided to allow for instrumentation power to be segregated from service power. The supply side of the two boxes are wired together, the separation capability exists for future requirements. The Backup Tower shed is powered from Highway 42 electrical transmission.

3.3 Surge Supression Panels

The signal cables from the primary and backup instrument sheds are buried in a common underground trench, which enters the plant in the Turbine Building basement, near the Waste Neutralizing Tank. The underground cables are terminated at a surge protection panel. This surge protection panel is provided to prevent voltage transients, caused by lightning or fault currents, from propagating into the plant. The inplant wiring is connected to the surge suppression panel. The panel was sized to utilize all wiring pairs; however, surge panels were provided only for the implemented signals. Spare pairs are terminated to a ground bus.

Surge protection is also provided for each signal input from the MET sensors to the associated shed instrumentation.

3.4 MET Power Distribution (See Figure KNP-MET02)

As previously described, the overall MET System is supplied from either a separate feed from Highway 42 or from MCC 1-46C.

In the event power from Highway 42 is lost, the primary tower continues to operate. A 480 VAC underground feed cable supplies a local transformer, which powers the primary tower instrumentation. The transformer is sized to accommodate the heating, cooling, and lighting loads of the primary shed if highway power is lost for an extended period. A manual throwover switch selects the source of power to the primary shed service circuits.

The backup tower is totally supplied from Highway 42 feed. Services and instrumentation circuits are divided into separate switch boxes in the event an arrangement similar to the Primary Tower is required in the future.

3.5 TSC Analog Racks (See Figure KNP-MET04)

Each MET signal on the primary and backup system is converted to a 4-20 ma signal and directly connected to the TSC rack installation. An allowance was made at the time of original installation for the attachment of computer inputs to each signal. The cable run to the TSC does not pass through the Relay Room.

Each TSC analog rack is energized from a separate circuit in the lighting panel located in the Conference Room area of the TSC basement.

- Primary and Backup rack is powered from: . . . LRPB1, Circuit 39.
- The supplemental rack is powered from: . . . . . LRPB1, Circuit 37.

The instrumentation power from the sheds supplies the power for the 4-20 ma signal loops; thus a de-energized Recorder Rack in the TSC does **not** inhibit plant computer acquisition of the MET Tower data.

As viewed from the front, the left TSC analog rack displays meteorological parameters from the backup tower. The supplemental Tower wind recorder is not connected. There is spare rack space for future instrumentation. The right side analog rack contains the meteorological readouts from the onsite primary and backup tower. The displayed parameters are as follows:

Primary Tower	Backup Tower
Multipoint Recorder: Sigma Theta Ambient Temperature Aspirator Status Differential Temp (delta T)	**Multipoint Recorder:** Sigma Theta Ambient Temperature Aspirator Status
Two-Pen Recorder: 10 meter level Wind Speed 10 meter Wind Direction	**Two-Pen Recorder:** 10 meter level Wind Speed 10 meter Wind Direction
Two-Pen Recorder: 60 meter level Wind Speed (0-100 mph) 60 meter level Wind Direction	

3.6 Wind Speed & Direction Systems

The wind speed and direction systems are identical for the 10-meter and 60-meter levels of the Primary Tower and for the Backup Tower. A three-cup anemometer measures wind speed and a wind vane senses the corresponding wind direction. Both the cup and the vane drive a separate transmitter. The output signal from the wind speed transmitter is a periodic square wave with a frequency proportional to the wind speed. The wind direction transmitter uses a digital optical encoder for increased accuracy over conventional potentiometer type transmitters.

In the shed/shelters, the wind speed processor converts the transmitter signal to a voltage between 0 and 5 volts to represent 0-50 mph at the 10 meter and 0-100 mph at the 60-meter level. The output signal from the wind direction processor is a DC voltage corresponding to wind vane angles 0-540°.

The wind system calibration sources are also included in the processors. These sources substitute fixed values into the processors for routine checks of the processor and recorders. The recorders are scaled so that the right side channels record wind speed from 0-50 mph or 0-100 mph. The left side channel records wind direction through a range of 0-540° (0-360-180°).

The output signal from the 10-meter wind direction processor is also analyzed for sigma, the standard deviation of the change in wind direction. The averaging time for sigma is set for 15 minutes. The output signal from the sigma processor is 0-5 volts, which corresponds to a range of 0-50°. The sigma data are recorded on the multipoint recorders in the shed and in the TSC. The sigma data is recorded in the 0 to 24 corresponding Pasquill categories.

3.7 Temperature Systems

Ambient air temperatures are measured by four wire platinum resistance temperature bulbs (RTBs), which are mounted in aspirated radiation shield assemblies at the 10 meter and 60 meter levels on the Primary Tower and the Backup Tower. The basic thermal radiation shield consists of an RTB holder, a fan, and a thermal radiation shield that protects the bulb from solar, atmospheric, and terrestrial thermal radiation interference. To ensure that the air sample monitored by the RTB is not stagnant air, the fan draws air across the surface of the RTB, thereby exposing the RTB to actual ambient air temperature at the monitored level. The resistance outputs from the RTBs are connected to the temperature signal conditioning processors located in the shed instrument racks.

On the Primary Tower, the processor amplifies the signals and determines the temperature differential (delta T) between the two levels. The temperature signal outputs from the processor amplifier consist of two data channels: the ambient temperature and the delta T between the upper and lower levels. The delta T outputs, which are 0-5 VDC, are input to the multipoint recorder. Ambient temperature is recorded from –40° to +120° F, and delta T (60 meter – 10 meter) is recorded from –2° F to +4° F. Ambient temperatures at the 60-meter level are not recorded.

A monitor processor monitors the status of the aspirator airflow. If the airflow through an aspirator stops, a light on the monitor front panel is illuminated, and the status trace on the multipoint recorder drops from a normal full-scale position to a predetermined level. For the backup tower, aspirator flow problems are indicated by a status trace at 50% of full scale. On the primary tower, a failure at the 60-meter level produces a trace at 66% of full scale. A failure at the 10-meter level produces a trace at half scale. If both aspirators fail at the same time, the chart trace drops to 40% of full scale.

3.8 Alarms

The following alarms are computer alarms. No Control Room annunciators are associated with this system.

M0001D	Primary Tower Door Switch	**CLOSED** = 1, **OPEN** = 0
M0002D	Primary Tower Door Ambient Shed Temp.	<90 and > 55 OK
M0021D	Backup Tower Door Switch	**CLOSED** = 1, **OPEN** = 0
M0022D	Backup Tower Door Ambient Shed Temp.	<90 and > 55 OK

4.0 Precautions And Limitations

There is no specific plant operating or abnormal procedures applicable to the MET System.

5.0 Reference

1.0 Summary	EPIP EP-ENV-3C, EP-ENV-3D,	EP-ENV-3G, EP-ENV-3H NUREG-0654 App. 2,	Reg. Guide 1.23 Rev. 1 Reg. Guide 1.97 NUREG 0737, Supplement 1.
2.0 Functions	10 CFR 50 Appendix I		
3.0 Design Description	MET Tech. Manual, XK-47204-1 through –15 A-406, E-3074, E-3190, E-3333 Annunciator Series - Computer Points M0001D, M0002D, M0021D, 0022D		
	For complete listing of DCRs associated with System 63, see: **Start\Apps\Modifications\Modifications Database\Search\Sys 63**		
4.0 Precautions & Limitations	There are no “Precautions & Limitations” applicable to System 63.		
5.0 References	There are no KNPP TS specific to System 63.		
6.0 Procedures	Refer to a controlled copy of KNPP procedures.		
7.0 Appendices	See attached Figures		

5.1 Technical Specifications (TS)

No specific TS are applicable to (MET) System 63. See appropriate System Descriptions listed below for radiological monitoring of KNPP site effluents:

- Radiation Monitoring (RM) System .... System Description 45
- Circulating Water (CW) System .... System Description 03
- Liquid Waste Discharge System .... System Description 32A
- Gaseous Radwaste Treatment (WG) .... System Description 32B
- Reactor Building Ventilation (RBV) System.. System Description 18
- Shield Building Ventilation (SBV) System ... System Description 24

6.0 Procedures

NOTE: Refer to a controlled copy of KNPP procedures.

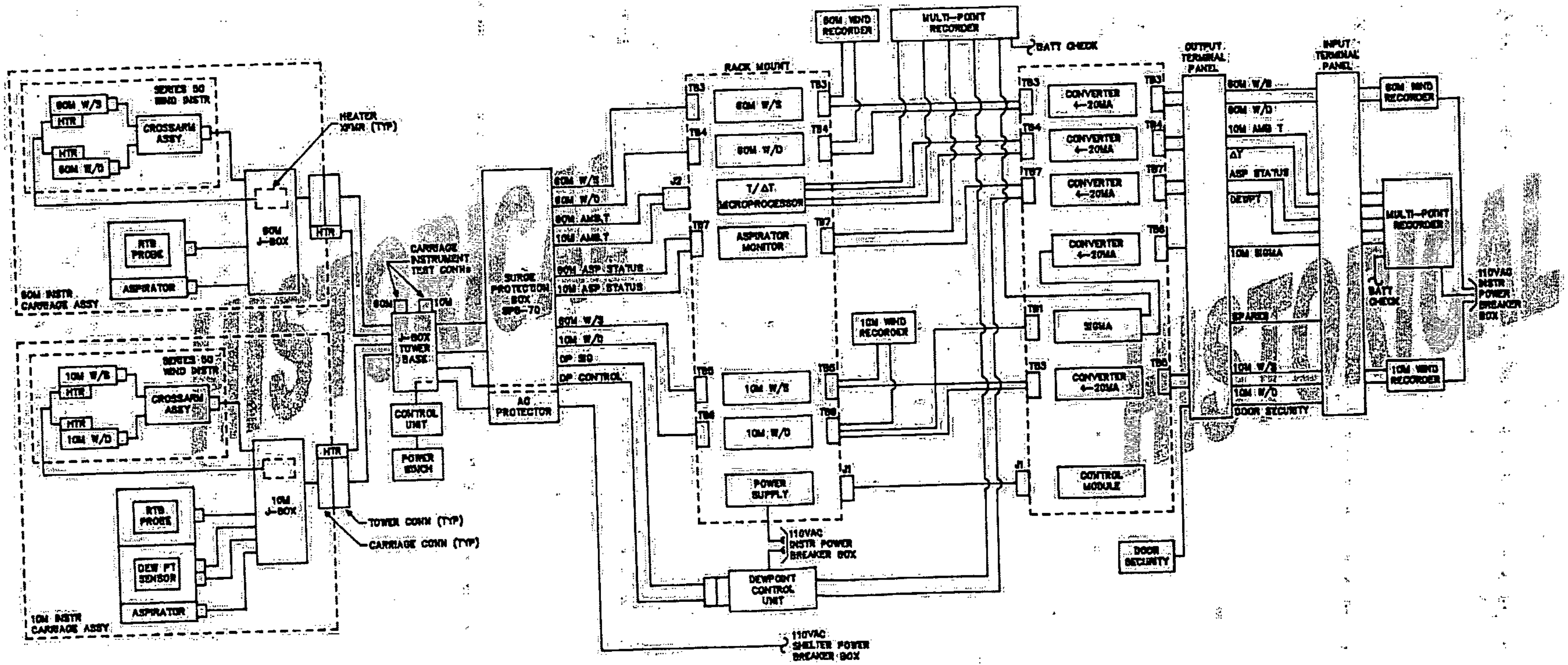
7.0 Appendices

7.1 Attached Figures

Figure	Title	KNPP DWGs
KNP-MET1	MET Parameters Monitored	XK-47204-11
KNP-MET2	MET Power Distribution	E-3333
KNP-MET3	60 Meter MET Tower	K-47204-13
KNP-MET4	TSC Met Recorders	E6002

NOTE: The "Figures" (drawings) previously associated with the System Descriptions are **not** being revised and updated at this time. Instead (obsolete) copies of these Figures have been watermarked **HISTORICAL** and temporarily attached. These Figures will be revised and replaced when resources become available.

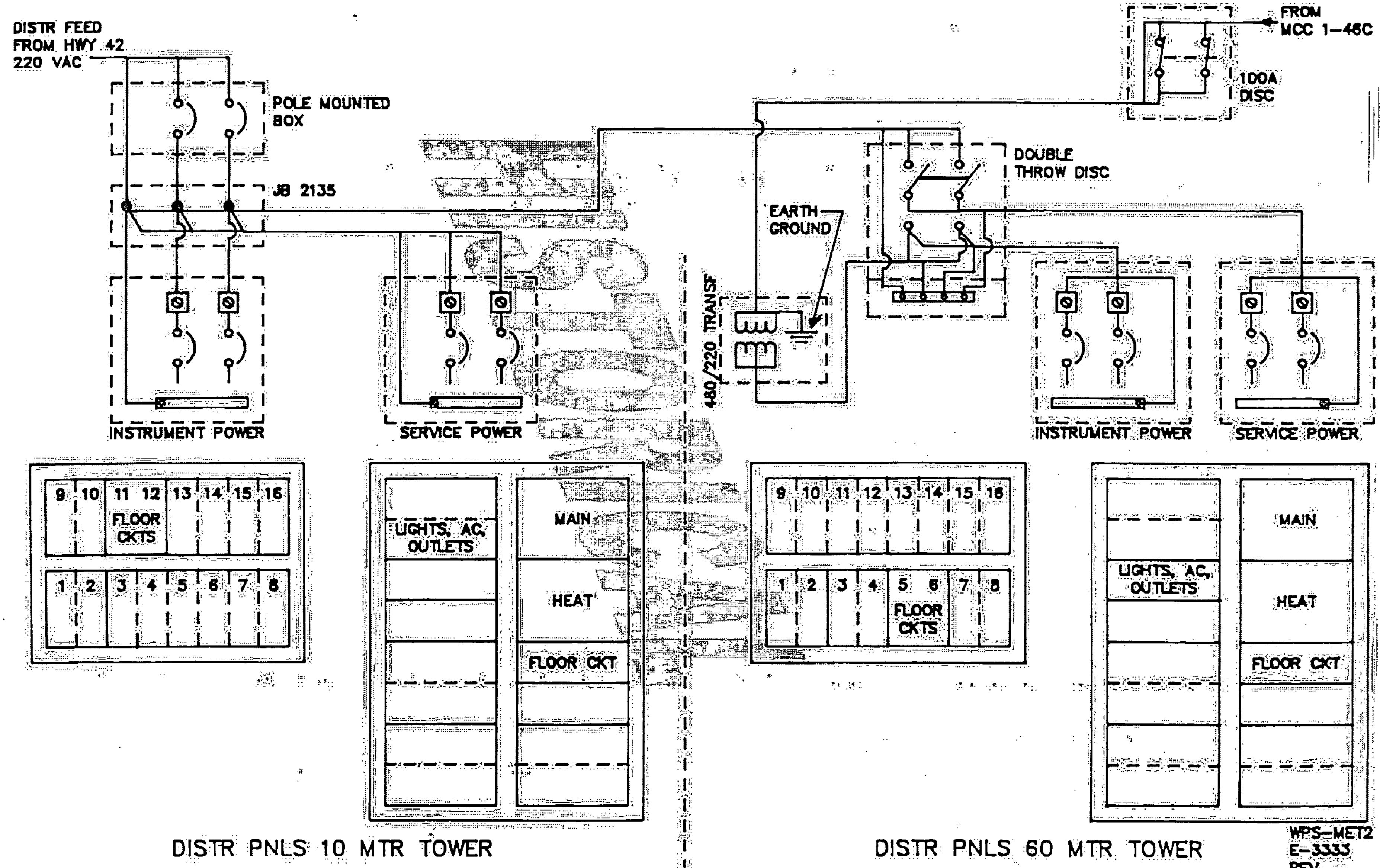
MET PARAMETERS
60 METER TOWER



WPS-MET1
2X-47204-11
REV. A
1-22-88

FOR TRAINING ONLY

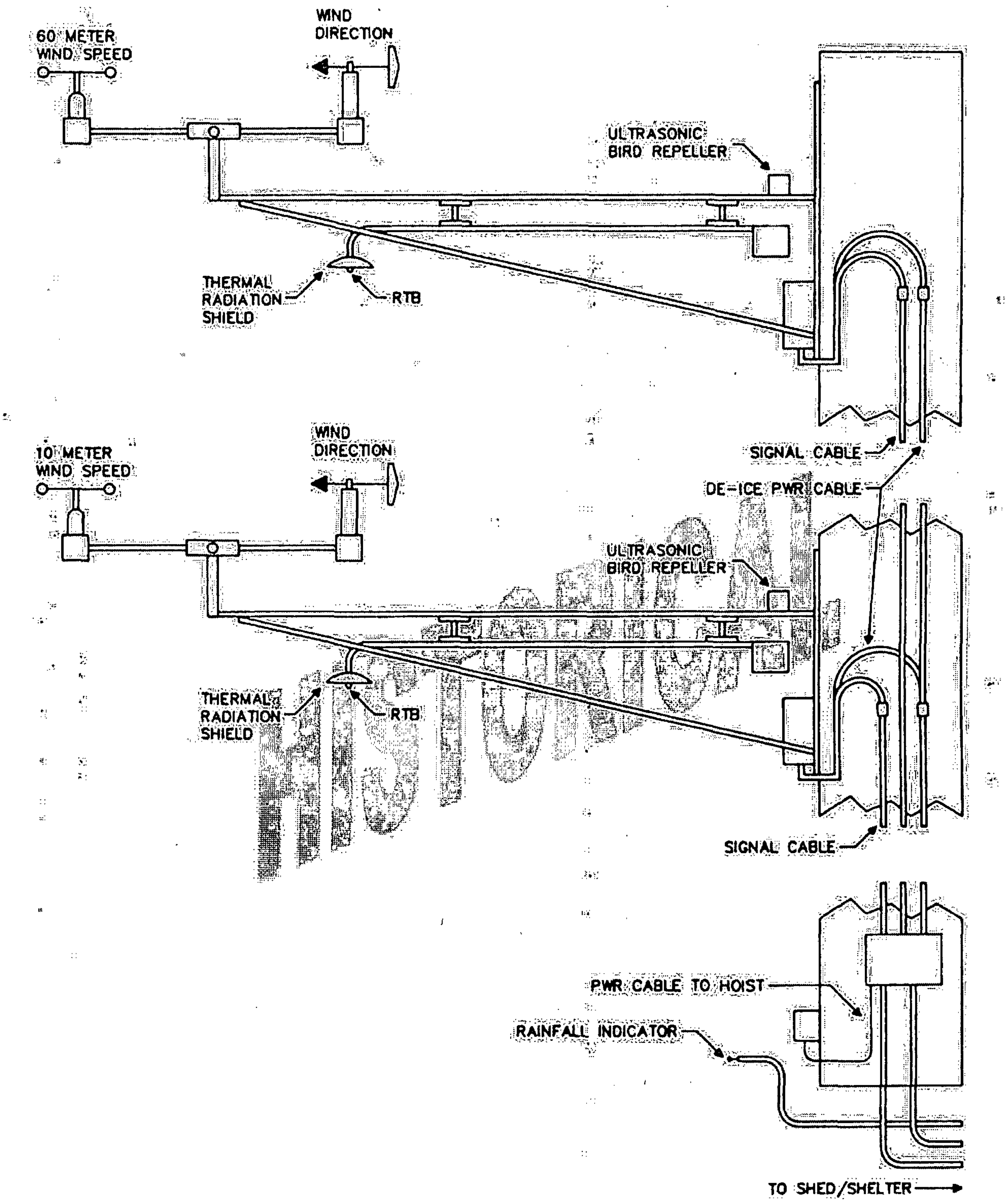
MET POWER DISTRIBUTION



FOR TRAINING ONLY

WPS-MET2
E-3333
REV. –
1-25-88

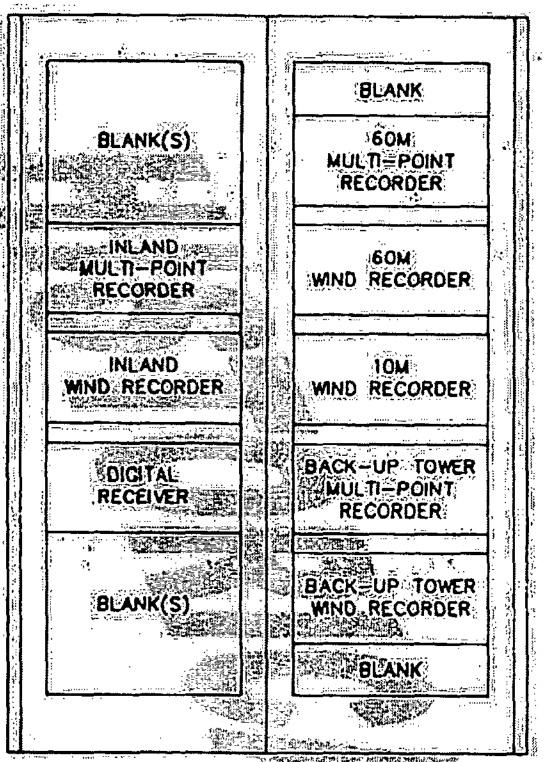
60 METER TOWER



WPS-MET3
K-47204-13
REV. A1
2-2-88

FOR TRAINING ONLY

TSC MET RECORDERS



FOR TRAINING ONLY

WPS-MET4
E6002
2-2-88

Dominion **KEWAUNEE POWER STATION**	PROCEDURE NO: **RP-KW-001-025** REVISION NO: **0**

PROCEDURE TYPE:

HEALTH PHYSICS

PROCEDURE TITLE:

METEOROLOGICAL MONITORING

Safety Related	PORC Review	SRO Approval Temp Change	System Number			
NO	NO	NO	63			

REVISION SUMMARY:

This revision 0 procedure is a new procedure. This revision 0 procedure is formatted in Framemaker to standards set forth in AD-AA-101-1002, Writers Guide for Procedures and Guidance and Reference Documents. This procedure provides a method of evaluating Met Tower data for the determination of system operability. The system will be evaluated on a quarterly basis to ensure the system is operable greater than 90% of the time.

INFORMATION USE

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1.0 PURPOSE

1.1 This procedure provides instructions to:

- Ensure meteorological instruments are monitored and maintained at a frequency that will provide data recovery of 90 percent on an annual basis. The 90 percent rate applies to the composite of all variables (e.g., the joint frequency distribution of wind speed, wind direction, stability class) needed to model atmospheric dispersion for each potential release pathway.
- Ensure the quality of data.
- Provide early identification of potential equipment problems.
- Ensure the licensing requirements for the Station, with regard to inspection of meteorological data and data review are being satisfied.
- Maintain an accurate met tower data set by assessing the validity of meteorological data.

1.2 This procedure addresses five types of activities:

- Daily meteorological data inspection activities
- Bi-weekly meteorological data processing activities
- Data analysis for comparison to 90% operability criteria
- Initiate actions based on comparison to 90% operability criteria
- Reporting activities

2.0 SPECIAL TOOLS AND EQUIPMENT

2.1 Plant Process Computer System (PPCS), Data Logger

3.0 PREREQUISITES

None

4.0 PRECAUTIONS AND LIMITATIONS

4.1 Precaution

4.1.1 Meteorological instrumentation specified in this procedure is required to be OPERABLE to meet meteorological data acquisition commitments as as described in Nuclear Regulatory Guide 1.23, Revision 1, (March 2007) Meteorological Monitoring Programs for Nuclear Power Plants. and may require emergency (non-routine) site visits by a qualified technician when instrument problems are identified.

4.2 Limitations

4.2.1 These activities are intended to help identify instrumentation failures. Early identification of instrumentation failure helps the Station achieve an annual data availability goal of 90% as required by Regulatory Guide 1.23.

4.2.2 The bi-weekly meteorological data processing activities are intended to produce a final data base. The information in this database is used to perform offsite dose assessments due to airborne gaseous radioactive effluents released each year.

4.2.3 The meteorological staff of the Dominion Weather Center at the Innsbrook Technical Center or their contract personnel assist Dominion staff in performing the tasks described in this procedure.

5.0 INSTRUCTIONS

5.1 Performing Daily Meteorological Data Inspection

5.1.1 Using the Plant Process Computer System (PPCS), Data Logger or equivalent, the Dominion weather center shall **REVIEW** the data during the normal work week from all of the on site met tower and channels reported.

a. IF any unreasonable values, given annual, seasonal and diurnal appropriateness, which may indicate suspected equipment malfunctions are identified, **THEN PERFORM** the following:

- **NOTIFY** Kewaunee Power Station (KPS) Chemistry personnel to review the data.
- **REPORT** any suspect values or instrument malfunctions to the Component Engineering Supervisor and Shift Manager.
- IF any data indicates suspected equipment malfunctions, **THEN COMPLETE** a Condition Report (CR) for non-conforming condition as required per the Corrective Action Program.
- **ENSURE** a Work Order is initiated, with appropriate priority based on Requlatory Guide 1.23 requirements of 90% availability status, to repair the equipment as soon as practicable.

5.1.2 IF Met Tower equipment is declared to be inoperable, **THEN DETERMINE** the time the equipment became inoperable and **PROVIDE** that information to the meteorological staff of the Dominion Weather Center [redacted].

5.1.3 WHEN notified that repairs have been completed and the equipment has been returned to operable status, **THEN PROVIDE** that information to the meteorological staff of the Dominion Weather Center.

5.2 Performing Meteorological Data Processing

5.2.1 Upon request, using the PPCS, Data Logger, or equivalent, listings of unedited primary tower and backup meteorological data sets may be provided by site Chemistry to the Dominion Weather Center.

5.2.2 The Dominion Weather Center shall **VERIFY** the data set collected from site instrumentation.

a. **EXAMINE** data and **PERFORM** the following:

- **COMPARE** alternate on site data sets for the same time block and long-term trends of single data sets.
- IF data is missing in the PPCS data set, THEN **REFER** to the data transfer from the Data Logger.
- **CONSIDER** known physical adjustments which have been made to the system or instruments or known existing situations documented.

> **NOTE:** Data NOT required by Regulatory Guide 1.23 may be edited when determined to be invalid and the editing should be annotated for equipment evaluation.

5.2.3 **VERIFY** an open CR addresses data required by Regulatory Guide 1.23 that is determined to be invalid or **INITIATE** a CR using the sites Central Reporting System.

[redacted]

5.2.4 The Dominion Weather Center shall **CHECK** data recovery rates.

a. **VERIFY** on a bi-weekly basis there is a recovery rate of at least 90 percent over the most recent 30 day period.

b. **WHEN** data validation for each quarter is complete, **THEN** :

- **IF** recovery rates for critical individual and joint parameters (e.g., WS, WD, and DT) are less than 90 percent in any quarter, **NOTIFY** RP Supervision and I&C Supervision at KPS and **ENSURE** a Condition Report is initiated a to correct the causes of data loss.
- **IF** recovery rates for critical individual and joint parameters are greater than 90 percent but less than 93 percent in any quarter, **THEN INFORM** the RP Supervision and Component Engineering Supervisor to evaluate elevating system priority to improve performance or reliability.
- **IF** recovery rates are greater than 93 percent, **THEN NO** actions are required.

NOTE: All data validation for the previous year shall be completed by February 28th of the following year.

c. **WHEN** data validation for each year is complete, **THEN NOTIFY** RP Supervision.

NOTE: Electronic data sets are electronically archived.

5.2.5 KPS Chemistry personnel shall **GENERATE** information for incorporating the data into the Annual Radioactive Release Report.

6.0 ACCEPTANCE AND SIGNOFF

6.1 Meteorological data is evaluated to ensure instruments are operable and providing data recovery of at least 90 percent on an annual basis.

6.2 Signoffs for compliance on operability status of the Met Tower is documented in the Annual Radioactive Release Report.

7.0 RECORDS

The following QA records and non-QA records are generated by or created according to this document and are listed on the KPS Records Retention Schedule. These records shall be maintained according to the KPS Records Management Program.

7.1 QA Records

Data produced by this procedure is documented within the Annual Radioactive Release Report.

7.2 Non-QA Records

None

8.0 ADMINISTRATIVE INFORMATION

8.1 Commitments

None

8.2 Definitions

None

8.3 References

8.3.1 Nuclear Regulatory Guide 1.23, Revision 1, (March 2007) Meteorological Monitoring Programs for Nuclear Power Plants

8.3.2 ICP-63-30, MET - Primary Tower Sensor Replacement, RTD and Processor Calibrations

8.3.3 N-MET-63, Meteorological Monitoring

8.3.4 Audit Finding 07-02-04K

AIR POLLUTION CONTROL OPERATION PERMIT RENEWAL

EI FACILITY NO: 431022790 PERMIT NO.: 431022790-F20

TYPE: Synthetic minor, non-Part 70

In compliance with the provisions of Chapter 285, Wis. Stats., and Chapters NR 400 to NR 499, Wis. Adm. Code,

Name of Source: Dominion Kewaunee Power Station

Street Address: N490 Highway 42
Kewaunee, Kewaunee County, Wisconsin

Responsible Official, & Title: Thomas J. Webb, Director of Safety & Licensing

is authorized to operate an electric generating facility in conformity with the conditions herein.

THIS OPERATION PERMIT EXPIRES **October 28, 2013**

A RENEWAL APPLICATION MUST BE SUBMITTED AT LEAST 6 MONTHS, BUT NOT MORE THAN 18 MONTHS, PRIOR TO THIS EXPIRATION DATE [ss. 285.66(3)(a), Wis. Stats. and NR 407.04(2), Wis. Adm. Code].

No permittee may continue operation of a source after the operation permit expires, unless the permittee submits a timely application for renewal of the permit. If you submit a timely application for renewal, the existing operation permit will not expire until the renewal application has been finally acted upon by DNR. [ss. 227.51(2), 285.62(8)(b), Wis. Stats. and NR 407.04(2), Wis. Adm. Code].

This authorization requires compliance by the permit holder with the emission limitations, monitoring requirements and other terms and conditions set forth in Parts I and II hereof.

Dated at Green Bay, Wisconsin, *10-28-2008*

STATE OF WISCONSIN
DEPARTMENT OF NATURAL RESOURCES
For the Secretary

By */s/ Richard Wulk*
Richard Wulk
Environmental Engineer Supervisor

PREAMBLE

An Asterisk (*) throughout this document denotes legal authority, limitations and conditions which are **not** federally enforceable.

Historical Summary of Permits/Orders Issued to the Facility.

Permit	Date Issued	Description
92-IRS-032	July 3, 1992	After-the-fact construction permit for TSC diesel generator, and construction permit for a 29.7 mmbtu/hour generator that was never built.
431022790-J01	November, 1992	Mandatory Operation Permit for the facility. Superseded by Permit #431022790-F01
431022790-F01	June 18, 1997	Original synthetic minor, non-Part 70 operation permit
431022790-F10	June 19, 2002	Operation permit renewal
431022790-F11	January 12, 2004	Revision to Permit #431022790-F10 to correct the permit expiration date.

The following permits, orders, etc. are adopted, under ss. 285.65(3), Wis. Stats., NR 406.11(1)(c) and (d), NR 407.09(2)(d) and NR 407.15(3) and (4), Wis. Adm. Code, by Permit 431022790-F20 which then becomes the primary enforceable document:

92-IRS-032

Stack and Process Index.

Stack and Process	Description	Capacity	Installation/Modification Date	Construction Permit?
S01, B01	Space heating boiler	35.7 million BTU per hour (mmbtu/hr)	1971	None; exempt
S02, B02	Emergency diesel generator 1A	28.7 mmbtu/hr	1971	None; exempt
S03, B03	Emergency diesel generator 1B	28.7 mmbtu/hr	1971	None; exempt
S04, B04	Emergency diesel generator TSC	6.734 mmbtu/hr	1981	92-IRS-032

Insignificant Emission Units

Maintenance of grounds, equipment and buildings (lawn care, painting, etc.)
Boiler, turbine and HVAC system maintenance (<5 MMBTU/hr.)
Internal Combustion Engines used for Warehousing and Material Transport
Fire control equipment
Janitorial activities
Office activities
Convenience water heating
Convenience space heating
Fuel oil storage tanks (<10,000 gal.)
Stockpiled contaminated soils
Demineralization and oxygen scavenging of water for boilers
Gravel parking areas
Tanks associated with insignificant emissions
Lubricating oil systems
100 KW LP backup generator power supply

Permit Shield — Unless precluded by the Administrator of the US EPA, compliance with all emission limitations in this operation permit is considered to be compliance with all emission limitations established under ss. 285.01 to 285.87, Wis. Stats., and emission limitations under the federal clean air act, that are applicable to the source if the permit includes the applicable limitation or if the Department determines that the emission limitations do not apply. The following emission limitations were reviewed in the analysis and preliminary determination and were determined not to apply to this stationary source:

None.

Part I — The headings for the areas in the permit are defined below. The legal authority for these limitations or methods follows them in [brackets].

Pollutant – This area will note which pollutant is being regulated by the permit.

Limitations – This area will list all applicable emission limitations that apply to the source, including case-by-case limitations such as Latest Available Control Techniques (LACT), Best Available Control Technology (BACT), or Lowest Achievable Emission Rate (LAER). It will also list any voluntary restrictions on hours of operation, raw material use, or production rate requested by the permittee to limit potential to emit.

Compliance Demonstration – The compliance demonstration methods outlined in this area may be used to demonstrate compliance with the associated emission limit or work practice standard listed under the corresponding **Limitations** column. The compliance demonstration area contains limits on parameters or other mechanisms that will be monitored periodically to ensure compliance with the limitations. The requirement to test as well as initial and periodic test schedules, if testing is required, will be stated here. Notwithstanding the compliance determination methods which the owner or operator of a sources is authorized to use under ch. NR 439, Wis. Adm. Code, the Department may use any relevant information or appropriate method to determine a source's compliance with applicable emission limitations.

Reference Test Methods, Recordkeeping, and Monitoring Requirements – Specific US EPA Reference test methods or other approved test methods will be contained in this area and are the methods that must be used whenever testing is required. A reference test method will be listed even if no testing is immediately required. Also included in this area are any recordkeeping requirements and their frequency and reporting requirements. Accuracy of monitoring equipment shall meet, at a minimum, the requirements of s. NR 439.055(3) and (4), Wis. Adm. Code, as specified in Part II of this permit.

Condition Type – This area will specify other conditions that are applicable to the entire facility that may not be tied to one specific pollutant.

Conditions – Specific conditions usually applicable to the entire facility or compliance requirements.

Compliance Demonstration – This area contains monitoring and testing requirements and methods to demonstrate compliance with the conditions.

PART II — This section contains the general limitations that the permittee must abide by. These requirements are standard for most sources of air pollutants so they are included in this section with every permit.

Part I

A. Stack S01, Boiler B01 - Space heating boiler rated at 35.7 million BTU per hour, installed or last modified in 1971.

POLLUTANT	a. LIMITATIONS	b. COMPLIANCE DEMONSTRATION	c. REFERENCE TEST METHODS, RECORDKEEPING AND MONITORING REQUIREMENTS
1.Particulate Matter Emissions	(1) Emissions may not exceed 1.0 pound per hour.[1] [ss. NR 404.08(2) and NR 415.06(1)(a), Wis. Adm. Code] (2) The stack height shall be no less than 92.8 feet above ground level.[2] [ss. 285.63(1)(b) and 285.65(3), Wis. Stats.]	(1) The permittee may burn only #1 and #2 fuel oil or used oil generated at the facility in this space heating boiler.[3] [s. NR 407.09(4)(a)3.b., Wis. Adm. Code]	(1) Whenever particulate matter emission testing is required, the permittee shall use US EPA Method 5, including backhalf emissions using US EPA Method 202. [ss. NR 439.06(1), Wis. Adm. Code] (2) The permittee shall keep records of the type and amount of fuel burned in the space heating boiler on a <u>monthly</u> basis. [s. NR 439.04(1)(d), Wis. Adm. Code; Permit #92-IRS-032] (3) The permittee shall keep and maintain on site technical drawings, blueprints or equivalent records of the physical stack parameters. [s. NR 439.04(1)(d), Wis. Adm. Code]
2. Visible Emissions	(1) 40% Opacity or number 2 on the Ringlemann chart. [s. NR 431.04(1), Wis. Adm. Code]	(1) The permittee may burn only #1 and #2 distillate fuel oil or used oil generated at the facility in this space heating boiler. [s. NR 407.09(4)(a)3.b., Wis. Adm. Code]	(1) Whenever visible emissions testing is required, the permittee shall use U. S. EPA Method 9. [s. NR 439.06(9)(a)1., Wis. Adm. Code] (2) The permittee shall keep records of the type and amount of fuel burned in the space heating boiler on a <u>monthly</u> basis. [s. NR 439.04(1)(d), Wis. Adm. Code; Permit #92-IRS-032]

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[1] The applicable particulate matter emission limit for this boiler is 0.60 pounds of particulate matter per mmBTU heat input. For this boiler, this equates to a maximum emission rate of 21.42 pounds per hour. However, modeling determined that in order to protect the National Ambient Air Quality Standard (NAAQS) for PM_{10} and the State standard for total suspended particulates (TSP), emissions must not exceed 1.0 pound per hour.

[2] This requirement is included because the source was modeled with this stack height and it was determined that no NAAQS or State standard would be violated at this stack height.

[3] Using a particulate matter emission factor for fuel oil combustion of 2 pounds per 1,000 gallons and a maximum burn rate of 255 gallons per hour, the maximum particulate matter emissions from distillate fuel oil combustion are 0.5 pounds per hour. Using a particulate matter emission factor for used oil combustion of 2.55 pounds per 1,000 gallons and a maximum burn rate of 79 gallons per hour, the particulate matter emissions from used oil combustion are 0.64 pounds per hour.

B. Stack S02, Unit B02 - Emergency Diesel Generator 1A (28.7 mmBTU/hr maximum heat input), installed or last modified in 1971.
Stack S03, Unit B03 - Emergency Diesel Generator 1B (28.7 mmBTU/hr maximum heat input), installed or last modified in 1971.

POLLUTANT	a. LIMITATIONS	b. COMPLIANCE DEMONSTRATION	c. REFERENCE TEST METHODS, RECORDKEEPING AND MONITORING REQUIREMENTS
1.Particulate Matter Emissions	(1) Emissions may not exceed 5.0 pounds per hour from <u>each</u> generator.[4] [ss. NR 404.08(2) and NR 485.055, Wis. Adm. Code] (2) The stack heights for these generators shall be no less than 93.5 feet above ground level.[5] [ss. 285.63(1)(b) and 285.65(3), Wis. Stats.]	(1) The permittee may burn only #1 and #2 fuel oil in these generators. [s. NR 407.09(4)(a)3.b., Wis. Adm. Code]	(1) Whenever particulate matter emission testing is required, the permittee shall use US EPA Method 5, including backhalf emissions using US EPA Method 202. [ss. NR 439.06(1), Wis. Adm. Code] (2) The permittee shall keep records of the type and amount of fuel burned in each generator on a <u>monthly</u> basis. [s. NR 439.04(1)(d), Wis. Adm. Code; Permit #92-IRS-032] (3) The permittee shall keep and maintain on site technical drawings, blueprints or equivalent records of the physical stack parameters. [s. NR 439.04(1)(d), Wis. Adm. Code]
2. Visible Emissions	(1) 40% Opacity or number 2 on the Ringlemann chart. [s. NR 431.04(1), Wis. Adm. Code]	(1) The permittee may burn only #1 and #2 distillate fuel oil in these generators. [s. NR 407.09(4)(a)3.b., Wis. Adm. Code]	(1) Whenever visible emissions testing is required, the permittee shall use U. S. EPA Method 9. [s. NR 439.06(9)(a)1., Wis. Adm. Code] (2) The permittee shall keep records of the type and amount of fuel burned in the space heating boiler on a <u>monthly</u> basis. [s. NR 439.04(1)(d), Wis. Adm. Code; Permit #92-IRS-032]
3. Nitrogen Oxides	(1) The permittee may not operate the generators more than 120 hours combined per month, averaged over any 12 consecutive months.[6] [s. 285.65(7) Wis. Stats., and 407.09(2)(d)2., Wis. Adm. Code; Permit #92-IRS-032]	(1) Within 15 days after the end of each month, the permittee shall calculate the combined monthly usage, in hours, of B02 and B03, averaged over the previous 12 months. [s. NR 407.09(4)(a)3.b., Wis. Adm. Code]	(1) <u>Reference Test Method for Nitrogen Oxide Emissions:</u> Whenever emission testing is required, the permittee shall use U.S. EPA Method 7, 7A, 7B, 7C, 7D or 7E. [s. NR 439.06(6)(a)., Wis. Adm. Code] (2) The permittee shall keep records of the number of hours each diesel generator is operated each month and the current monthly average identified in Condition B.3.b.(1). [s. NR 439.04(1)(d) Wis. Adm. Code]

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[4] The applicable particulate matter emission limit for these generators is 0.50 pounds of particulate matter per mmBTU heat input. For these generators, this equates to a maximum emission rate of 14.35 pounds per hour each. However, modeling determined that in order to protect the National Ambient Air Quality Standard (NAAQS) for PM_{10} and the State standard for total suspended particulates (TSP), emissions must not exceed 5.0 pounds per hour each.

[5] This requirement is included because the source was modeled with these stack heights and it was determined that no NAAQS or State standard would be violated at these stack heights.

[6] The permittee elected to take this limit in order to restrict nitrogen oxide emissions to below the Part 70 threshold.

C. Stack S04, Unit B04 - Emergency Diesel Generator TSC (6.734 mmBTU/hr maximum heat input), installed in 1981.

POLLUTANT	a. LIMITATIONS	b. COMPLIANCE DEMONSTRATION	c. REFERENCE TEST METHODS, RECORDKEEPING AND MONITORING REQUIREMENTS
1.Particulate Matter Emissions	(1) Emissions may not exceed 1.1 pounds per hour.[7] [ss. NR 404.08(2) and NR 485.055, Wis. Adm. Code] (2) The stack height shall be no less than 34.8 feet above ground level.[8] [ss. 285.63(1)(b) and 285.65(3), Wis. Stats.]	(1) The permittee may burn only #1 and #2 fuel oil in this generator. [s. NR 407.09(4)(a)3.b., Wis. Adm. Code]	(1) Whenever particulate matter emission testing is required, the permittee shall use US EPA Method 5, including backhalf emissions using US EPA Method 202. [ss. NR 439.06(1), Wis. Adm. Code; Permit #92-IRS-032] (2) The permittee shall keep records of the type and amount of fuel burned in each generator on a monthly basis. [s. NR 439.04(1)(d), Wis. Adm. Code; Permit #92-IRS-032] (3) The permittee shall keep and maintain on site technical drawings, blueprints or equivalent records of the physical stack parameters. [s. NR 439.04(1)(d), Wis. Adm. Code]
2. Visible Emissions	(1) 20% Opacity or number 1 on the Ringlemann chart. [s. NR 431.05, Wis. Adm. Code Permit #92-IRS-032]	(1) The permittee may burn only #1 and #2 fuel oil in this generator. [s. NR 407.09(4)(a)3.b., Wis. Adm. Code]	(1) Reference Test Method for Visible Emissions: Whenever visible emission testing is required, the permittee shall use U.S. EPA Method 9. [s. NR 439.06(9)(a)1., Wis. Adm. Code; Permit #92-IRS-032] (2) The permittee shall keep records of the type and amount of fuel burned in this generator on a monthly basis. [s. NR 439.04(1)(d), Wis. Adm. Code; Permit #92-IRS-032]
3. Nitrogen Oxides	(1) The permittee may not operate the generator more than 60 hours per month, averaged over any 12 consecutive months.[9] [s. 285.65(7) Wis. Stats., and 407.09(2)(d)2., Wis. Adm. Code; Permit #92-IRS-032]	(1) Within 15 days after the end of each month, the permittee shall calculate the monthly usage, in hours, this generator, averaged over the previous 12 months. [s. NR 407.09(4)(a)3.b., Wis. Adm. Code]	(1) Reference Test Method for Nitrogen Oxide Emissions: Whenever emission testing is required, the permittee shall use U.S. EPA Method 7, 7A, 7B, 7C, 7D or 7E. [s. NR 439.06(6)(a)., Wis. Adm. Code] (2) The permittee shall keep records of the number of hours this generator is operated each month and the current monthly average identified in I.C.3.b.(1). [s. NR 439.04(1)(d) Wis. Adm. Code]

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[7] The applicable particulate matter emission limit for these generators is 0.50 pounds of particulate matter per mmBTU heat input. For these generators, this equates to a maximum emission rate of 14.35 pounds per hour each. However, modeling determined a lower emission rate was needed to protect the National Ambient Air Quality Standard (NAAQS) for PM_{10} and the State standard for total suspended particulates (TSP).

[8] This requirement is included because the source was modeled with these stack heights and it was determined that no NAAQS or State standard would be violated at these stack heights.

[9] The permittee elected to take this limit in order to restrict nitrogen oxide emissions to below the Part 70 threshold.

D. Conditions Applicable to the Entire Facility	
CONDITION TYPE	**a. SPECIFIC CONDITIONS**
1. Compliance Testing	(1) All testing shall be performed while the emissions unit is operating at capacity. If operation at capacity is not feasible the source shall operate at a level which is approved by the Department in writing [s. NR 439.07(1), Wis. Adm. Code] (2) The Department shall be informed at least 20 working days prior to the tests so that a department representative can witness the testing. At the time of notification, a compliance test plan shall be submitted for approval. [s. NR 439.07(2), Wis. Adm. Code] (3) Two copies of the report on the test results shall be submitted to the Department for evaluation within 60 days after completion of the tests. [s. NR 439.07(9), Wis. Adm. Code]
2. Recordkeeping	(1) Copies of all records required under this section shall be retained by the owner or operator for a period of 5 years or for such other period as may be specified by the department. [s. NR 439.04(2) Wis. Adm. Code] (2) These records shall be made available to authorized department personnel upon request. [s. NR 439.05 Wis. Adm. Code]
3. Reporting	(1) The permittee shall submit the results of monitoring or a summary of monitoring results required by this permit to the Wisconsin Department of Natural Resources, Northeast Region Air Program, 2984 Shawano Avenue, PO Box 10448, Green Bay, WI 54307-0448, on an <u>annual</u> basis. (a) The time period to be addressed by the submittal is the January 1 to December 31 period which precedes the report. (b) The reports shall be submitted by March 1 of each year. (c) All deviations from and violations of applicable requirements shall be clearly identified in the submittals. (d) Each submittal shall be certified by a responsible official as to the truth, accuracy and completeness of the report. [s. NR 439.03(1)(b), Wis. Adm. Code] (2) Submit an <u>annual</u> certification of compliance with the requirements of this permit to the Wisconsin Department of Natural Resources, Northeast Region Air Program, 2984 Shawano Avenue, PO Box 10448, Green Bay, WI 54307-0448. (a) The time period to be addressed by the report is the January 1 to December 31 period which precedes the report. (b) The certification of compliance shall be submitted by March 1 of each year. (c) The information included in the report shall comply with the requirements of Part II Section N of this permit. (d) Each certification of compliance shall be certified by a responsible official as to the truth, accuracy and completeness of the report. [s. NR 439.03(1)(c), Wis. Adm. Code]
4. Alternate Operating Scenario: Use of raw materials not included in the permit application	(1) If the permittee uses a raw material not included in the application reviewed for this permit, the following requirements shall be met by the permittee: (a) The source has continuously had such design capability to burn or use the raw material. (b) The use will not cause or exacerbate the violation of an ambient air quality standard or an ambient air increment. (c) The use is not prohibited by any permit, plan approval or special order applicable to the source. (d) The use will not result in a violation of any emission limit in chs. NR 405, 408, 409, 415 to 436, and 445, Wis. Adm. Code. (e) The use will not subject the source to any standard or regulation under s. 112 of the Clean Air Act (42 USC 7412). [ss. NR 406.04(4)(a), NR 407.09(1)(c)2. and 439.04(1)(d), Wis. Adm. Code] (2) Any calculations and supporting material required to demonstrate compliance with Condition D.4.a.(1) shall be kept on file by the permittee. [ss. NR 407.09(1)(c)2. and NR 439.04(1)(d), Wis. Adm. Code]

D. Conditions Applicable to the Entire Facility	
CONDITION TYPE	**a. SPECIFIC CONDITIONS**
5. Malfunction Prevention and Abatement Plan	(1) The permittee shall prepare and keep on file a Malfunction Prevention and Abatement Plan to prevent, detect and correct malfunctions or equipment failures which may cause any applicable emission limitation to be violated or which may cause air pollution. This Malfunction Prevention and Abatement Plan shall include: (a) Identification of the individual responsible for inspecting, maintaining and repairing the air pollution control equipment. (b) The maximum intervals for inspection and routine maintenance of the air pollution control equipment. The maximum interval for routine inspection and maintenance may not exceed that recommended by the manufacturer unless otherwise specified in the Malfunction Prevention and Abatement Plan. (c) A description of the items or conditions that will be checked. (d) A listing of materials and spare parts that will be maintained in inventory. (e) A description of the corrective procedures that will be taken in the event of a malfunction or failure which results in the exceedance of the applicable emission limitation. These corrective procedures shall achieve and maintain compliance with the applicable emission limitations as expeditiously as possible but not longer than the time necessary to discontinue operation of the source consistent with safe operating procedures. (f) A description of the activities and maximum intervals for routine maintenance and inspection of instrumentation installed and operated to monitor the operation of air pollution control equipment as required under s. NR 439.055(1), Wis. Adm. Code. The maximum interval for inspection and routine maintenance may not exceed that recommended by the manufacturer of the instrumentation unless otherwise specified in the Malfunction Prevention and Abatement Plan. (g) The calibration schedule for any device which monitors either a source or air pollution control equipment operational variables. The time between calibrations may not exceed one year or as specified in the Malfunction Prevention and Abatement Plan, whichever is shorter. (h) Such other information as the Department may deem pertinent. [ss. NR 407.09(4)(a)3. and 439.11(1), Wis. Adm. Code] (2) The Malfunction Prevention and Abatement Plans shall be updated at least once every five years. [ss. NR 407.09(4)(a)3. and 439.11(1), Wis. Adm. Code]

D. Conditions Applicable to the Entire Facility	
CONDITION TYPE	**a. SPECIFIC CONDITIONS**
6. *NR 445 Reporting, Recordkeeping and Compliance Requirements	(1) *If the permittee has non-exempt, potential to emit emissions of any hazardous air contaminants less than or equal to the applicable threshold in column (c), (d), (e) or (f) of Table A, B or C of s. NR 445.07, Wis. Adm. Code, then the permittee shall maintain records in accordance with s. NR 439.04(1) and (2), Wis. Adm. Code starting no later than June 30, 2007. [s. NR *445.08(6)(b), Wis. Adm. Code] (2) *To meet the requirements of Condition D.6.a.(1), the permittee shall, at a minimum, keep records of the calculations of non-exempt, potential to emit emissions of each hazardous air contaminant emitted by the facility in amounts less than or equal to the applicable threshold value in Tables A, B or C of s. NR 445.07, Wis. Adm. Code. Calculations shall include the emission factors used to calculate emissions, and the source of the emission factors. [s. NR 439.04(1)(d), Wis. Adm. Code] (3) *If the permittee has non-exempt, potential to emit emissions of any hazardous air contaminant greater than the applicable threshold in column (c), (d), (e) or (f) of Table A, B or C of s. NR 445.07, Wis. Adm. Code, then the permittee shall do all of the following: (a) *Submit information no later than December 31, 2005, in accordance with the procedure in s. NR 445.08(7)(a), Wis. Adm. Code, adequate to describe how applicable control requirements in ss. NR *445.07(1)(c) or *445.09(3), Wis. Adm. Code, will be met. (b) *Achieve compliance with applicable emission limitations and control requirements in accordance with s. NR *445.08(1) and (2) no later than June 30, 2007. (c) *Submit the required information in accordance with s. NR *445.08(7), Wis. Adm. Code. [s. NR *445.08(6)(c), Wis. Adm. Code] (4) *If the permittee is required to achieve compliance in accordance with Condition D.6.a.(3), then the permittee shall demonstrate compliance by doing the following as applicable: (a) *Submit the information required under s. NR 445.08(6)(c)1., Wis. Adm. Code, on the application form required for an operation permit, an amendment to an application, renewal of the operation permit, or for a significant revision under s. NR 407.13, Wis. Adm. Code, as applicable. (b) *Submit all of the following information to the Department: (i) The hazardous air contaminants in Table A, B and C of s. NR 445.07, Wis. Adm. Code, the facility is capable of emitting in an amount greater than the threshold value listed for the contaminant in the applicable table. (ii) The emission limitation applicable to each hazardous air contaminant identified under Condition D.6.a.(4)(b)(i). (iii) The method or combination of methods used for achieving compliance under ss. NR 445.08(2) or (3), Wis. Adm. Code with the applicable standard for each hazardous air contaminant. (iv) A description of the records that will be kept on site to verify continuous compliance for each hazardous air contaminant and its applicable standard. (v) A signed and dated statement by the responsible official stating that the information is accurate to the best of his or her knowledge and belief, and that all of the requirements of ch. NR 445, Subchapter III have been met. (vi) The address for submittal of this information is Wisconsin Department of Natural Resources, Bureau of Air Management, PO Box 7921, Madison WI 53707-7921, Attention: NR 445 Compliance Notifications. [s. NR *445.08(7), Wis. Adm. Code]

ENCLOSURE B

TERRESTRIAL ECOLOGY

Documents Included in this Enclosure

1. Documentation/correspondence related to diving ducks in the intake between Dominion and DNR 7/28/08 letter (requested during terrestrial interview)
2. Documentation of size of wetland near ISFSI that has been delineated 5/27/09 email (requested during terrestrial interview)
3. Terrestrial survey of Kewaunee site, 2006-2007 (redacted version)
4. ATC transmission line right-of-way vegetation management specification, August 2008

KEWAUNEE POWER STATION
DOMINION ENERGY KEWAUNEE, INC.

Dominion Generation
4111 Castlewood Road, Richmond, VA 23234

Dominion

July 28, 2008

MISC-2008-0029

Mr. Steve Stoinski
U.S. Fish and Wildlife Service
Division of Law Enforcement
2661 Scott Tower Drive
New Franken, WI 54229

RE: Kewaunee Power Station Migratory Bird Incidental Taking

Dear Mr. Stoinski:

Attached is the independent review regarding the incidental taking of migratory birds by the Kewaunee Power Station (KPS) cooling water intake system. KPS contracted with STS Consultants of Green Bay to perform this independent review which included trying to understand how these incidents occur considering the biology of these diving birds, contacting other nearby water users, evaluating potential solutions and discussing the relative significance of the issue.

The study indicates that there is no simple solution for this issue. A cost-benefit analysis indicates that the costs for engineered solutions far exceed the environmental benefits. In addition, engineered solutions can often result in negative environmental impacts.

This year there have been no large flocks of diving birds congregating near the intakes as has been the case in other years. Consequently, there have been no diving bird mortalities noted at the station in 2008.

Based on the findings of the independent review, and this year's lack of incidents, KPS recommends that no additional actions are warranted at this time.

If you have any questions, please contact either Mr. Ted Maloney at (920) 388-8863 or Mr. Bill Bolin at (804) 271-5304.

Sincerely,

Steve Bolin for PFF

Pamela F. Faggert
Vice President and Chief Environmental Officer

Enclosure

Dominion

Dominion Resources, Inc.

Kewaunee Power Station

Summary of Findings, Dominion Migratory Waterfowl Incidental Taking Issue

Submitted to

U.S. Fish and Wildlife Service
Division of Law Enforcement
2661 Scott Tower Drive
New Franken, WI 54229

July 28, 2008

STS | AECOM

STS
1035 Kepler Drive, Green Bay, Wisconsin 54311
T 920.468.1978 F 920.468.3312

Technical Memorandum

Date: April 29, 2008

To: Ted Maloney, Bill Bolin - Dominion Energy Kewaunee

From: Jan Tesch, Steven Shimek - STS

Subject: Summary of Findings, Dominion Migratory Waterfowl Incidental Taking Issue – STS Project No. 200705952

1.0 Background

Dominion Energy Kewaunee, Inc. (DEK) is located on the west shore of Lake Michigan in the township of Carlton, approximately 8 miles south of Kewaunee and 90 miles north of Milwaukee, Wisconsin. The facility employs a single pressurized water reactor nuclear generating unit and produces a net output of 575 megawatts electric (MWe). The station is classified as a base load unit that normally operates 24 hours per day and 7 days per week. The power station began commercial operation on December 21, 1973, and was purchased by Dominion Energy from Wisconsin Public Service Corporation on July 5, 2005.

An integral component of the type of power generation system employed at DEK is the operation of a circulating "once-through" water system to provide water to generate steam and cool various components of the power generator. The water circulation system at DEK was designed to provide a reliable supply of water from Lake Michigan to the power plant, regardless of weather or lake conditions. The intake for the power generating system is located approximately 1,700 feet off-shore at a point approximately 450 feet outboard of the known maximum ice windrow development zone paralleling the shoreline. Water depth at the intake for the circulating water system was calculated to be 14 feet below the normal surface water level (indicated as +577.0 feet in 1969[1]) to avoid the surface ice blanket.

DEK records and reports all incidental wildlife occurrences and those not related to station operations. Records have been kept at DEK since 2006. These records demonstrate periodic events of diving ducks entrained in the station's circulating water system. The ducks enter the off shore intake while foraging for food and subsequently drown in the intake pipes. They lodge against the trash screens in the intake forebay where they are collected, identified, recorded, and reported to the US Fish and Wildlife Services (FWS).

The FWS requested that DEK perform a study to determine if there was a practical and feasible method to prevent waterfowl entrainment.

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[1] As shown on Dominion Energy Kewaunee Circulating Water Intake Plan and Profile S-614 dated 4-26-69 revised 12-13-69.

2.0 Description of Cooling Water Intake System

The circulating water system consists of a submerged, off-shore structure that contains a cluster of three vertical 22-foot diameter primary inlet cones, each surrounded by concrete footing protruding approximately 1 foot above the lake floor. The vertical cones feed water through 6-foot diameter steel pipes, which join at a trifurcation into one 10-foot interior diameter, asphalt-coated steel pipe buried approximately 3 feet below the lake bottom leading to the power station. There are also two auxiliary water intake structures on the main intake pipe located at 50 feet and 100 feet shoreward of the primary intake cones. The auxiliary intakes consist of 30-inch diameter vertical tee pipes that extend from the main intake pipe to approximately 1 foot above the lake floor. The primary intake cones are covered by trash grills with 2-foot square openings to prevent logs and large debris from entering the circulation system and reduce opportunities for winter frazzle ice formation. The auxiliary inlets also have special screened cover plates with 12-inch openings to exclude entrainment of debris.

The primary inlet cones and auxiliary inlets were designed or positioned on the lake floor so that the largest lake barge cannot directly cover all the inlets simultaneously. Any four of the inlets could be blocked and still leave an open inlet with a capacity greater than the 24,000 gpm required for plant operation. Spacing of the cones maintains the velocity of water at the surface grids during full plant load (two circulation pumps operating) at less than 1 foot per second (fps).[2]

Water from the intake pipe enters into the station through the forebay, a rectangular concrete structure having a maximum capacity of approximately 317,000 gallons of water. Four woven wire traveling screens (3/8-inch mesh openings) are located in the forebay ahead of two centrifugal circulation pumps. The screens collect debris or other items in the intake water. Debris and impinged organisms are flushed off the screens and returned to the outfall stream.

Intake water from the forebay feeds the circulating water system and separates service water and fire protection systems. The centrifugal circulation pumps are each designed to supply 210,000 gpm. During warm weather months, it is usual for both circulating pumps to be operated simultaneously. When the ambient temperature of Lake Michigan becomes seasonally cooler, the plant will operate with only one circulating pump. During normal operation, three service water pumps are usually operated, but the number of pumps can vary from two to four based on what is required to keep the system at optimum pressure.

3.0 Attraction of Migratory Waterfowl to Waters Off-shore of DEK

Lake Michigan, off shore of the DEK power plant, is attractive to fish and waterfowl for various reasons. Observation Point, a slight bump-out of the Lake Michigan shoreline, is located immediately south of the DEK facility (Figure 1 - Location Diagram). The shoreline to the north of Observation Point retreats back to the west, and then turns gradually to the northeast, forming a large, open cove that may offer some protection of the near shore area from predominantly westerly and northerly winter winds . Discharge water from the station may also allow the near shore area by the DEK facility to remain free of ice longer into the winter season than surrounding waters, and conversely clears the area of ice earlier in the spring. This may

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[2] Maloney, T., Dominion Energy Kewaunee Sr. Environmental Compliance Coordinator, Personal Communication, January 4, 2008.

encourage waterfowl to remain in the area for longer periods of time during migratory stopovers. There are also three small inland streams entering Lake Michigan along the shoreline to the north and south of DEK that contribute fresh runoff to the near-shore zone. The runoff brings with it nutrients, organic matter, and potential food sources for various forms of aquatic life, and may contribute to the food web in the immediate vicinity of DEK.

Changes to the Great Lakes ecosystem brought about by the introduction of invasive species may also have increased the attractiveness of the DEK lakeshore, specifically to certain species of waterfowl. Research has found that the food habits of diving ducks in the Great Lakes are changing due to the increasing availability of Zebra mussels. Zebra mussels were introduced into North America during the mid-1980s, and are now a dominant member of many benthic communities in the Lower Great Lakes.[3] The diet of Common Goldeneye in Lake Erie was found to be nearly 80% Zebra mussels, wherein the past the winter diet was reported to be wild celery winter buds, oligochaetes, decapods, crustaceans and insects, and trace amounts of mollusks.[4] Lesser Scaup and Bufflehead are also known to feed extensively on Zebra mussel in western Lake Erie.[5] It can, therefore, be assumed the diving ducks in Lake Michigan would feed on Zebra mussels as a primary winter food.

In the early stages of the Zebra mussel invasion, it was thought that Zebra mussels could only colonize hard substrates, and soft substrate would not be suitable for colonization because Zebra mussel veligers (larvae) appeared to thrive best where they could attach themselves by strong byssus threads to stationary hard surfaces. Recent investigations have found that Zebra mussels also can colonize sand and muddy substrates by binding sand grains together with their byssus threads, creating a conglomerate, or mass that is subsequently settled by juveniles, eventually creating a bed of Zebra mussels on the lake bottom.[6] Soil exploration completed prior to construction of the DEK intake structure indicated the presence of clay and silty clay (DEK Plan Profile S-614) substrate in the area of the DEK intake. Rocky areas are also known to occur in the vicinity as well as areas with loose rocks and cobbles.[7] The mixed substrate (rocks, cobbles, and clay) in the area of the DEK is suitable for mussel colonization. Zebra mussel colonization offshore of the DEK would provide ample quantities of winter food for migrating waterfowl.

Findings - The area offshore of the DEK is attractive to migrating waterfowl. A concentration of migrating diving ducks in the general area of DEK for potentially longer time durations may increase the potential for duck entrainment.

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[3] MacIsaac, H., Population structure of an introduced species (Dreissena polymorpha) along a wave-swept disturbance gradient, 1995.

[4] USGS Northern Prairie Wildlife Research Center, Food Habits of Diving Ducks in the Great Lakes after the Zebra Mussel Invasion, A Discussion, August 2006.

[5] MacIsaac, H., Potential Abiotic and Biotic Impacts of Zebra Mussels on the Inland Waters of North America, 1996.

[6] Ohio State University, Study Shows Zebra Mussels Can Colonize Sand and Mud, Science Daily, May 1998.

[7] Janssen, J., Berg, M., Lozano, S., Submerged terra incognita: Lake Michigan's abundant but unknown rocky zones, *Aquatic Ecosystems Health and Management Society, 2005.*

4.0 Duck Entrainment

Duck species that frequent large open water bodies and dive underwater to forage for fish and various benthic organisms are commonly referred to as diving ducks. During the late fall and early spring migratory periods, DEK personnel have observed large rafts of diving ducks in the open water off shore of the power station. The ducks stay in the area for approximately a month, and then leave either as weather conditions deteriorate to make them move southward, or improve in spring to allow them to return on the journey north to breeding grounds. During the migratory stop-over, some species of diving ducks have become entrained in the intake pipe in varying amounts. A review of various reference materials on duck behavior and foraging habits suggests that the ducks are diving from the surface down 12 to 15 feet to the lake bed to feed on Zebra mussels, small fish, or benthos in the area of the intake cones.

The recorded waterfowl fatality list[8] complied since February 2006 has included five species of diving ducks that were entrained in the water intake system:

- Common goldeneye
- Barrows goldeneye
- Mergansers (species not identified)
- Bufflehead
- Scaup (identified as Bluebill - species not identified)

The majority of the fatalities over the greatest time period are those ducks that are reported to forage on Zebra mussels, specifically the Goldeneye, Bufflehead, and Scaup. Merganser fatalities were only reported on a single event, but at a higher number than all other duck fatalities combined over a two-year period. The differences in fatality numbers may be related to the different feeding habits of the ducks. Mergansers feed on fish, and it can be speculated that the Mergansers were feeding on a school of fish that were moving or feeding in or around the intake. The fish may have used the angles and grates of the intake structure as a man-made reef to evade the ducks, and the ducks followed them into the structure. The other ducks were entrained in small numbers at different times in the spring and fall, which would suggest that these ducks were randomly feeding on the bottom near the intake area. Mike Holdridge (Seaview Diving), who has been contracted by DEK to inspect the intake structure and pipe, related to STS that Zebra mussels are present on the grating covering the intakes even though they have been coated with an antifouling agent. The Zebra mussels also cling to algae coating the inside of the intake structure and are present in greater numbers than those on the grates.[9] The ducks may be foraging along the lake bottom and continue uninhibited into the intake cones while foraging on the Zebra mussels The velocity of the water at the intake surface is less than 1 fps, even at maximum system capacity when both circulation

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[8] Dominion Energy Kewaunee Power Station Duck Log (Appendix).

[9] Holdridge, Mike, Seaview Diving, Personnel Communication, January 15, 2008.

pumps are operating. Holdridge and Maloney both indicated that even at maximum flow, a vortex flow was not present at the surface of the intake cones. A fish or bird should be able to swim free of a current of this velocity if they are beyond the grated surface of the cone. Therefore, the assumption is that the ducks are venturing too far into the intake piping, cannot find their way back out, and are swept along by the intake current into the system.

Findings - It may be generally surmised that the ducks are becoming entrained because they are feeding within the intake cones, and not being drawn into the intake structure by swimming in the general area of the intakes.

5.0 Industry Contacts and Response

STS inquired with several other power generating plants that have circulating water intake systems and municipal water utilities operating raw water intakes located on the west shore of Lake Michigan about the type of intake structure in use at their facilities, whether diving duck entrainment occurred, and if so what, if anything, had been implemented to prevent or reduce the incidence of entrainment. The object of gathering the data was to determine if something could be identified as a key element, or difference in the DEK intake when compared with other intakes, that would make ducks more susceptible to entrainment in it, or conversely factor in as a reason that duck entrainment is avoided or reduced at other facilities. These factors could be things such as the structure design, the location of the structure (substrate type or water depth, etc.), or any in-place deterrent system. The contact and response data is shown in Table 1.0 - Contact and Response Data Summary.

Findings - Entrainment of diving ducks in water systems along the west shore of Lake Michigan is not a common problem for the facilities contacted by STS. Intake systems that are further off shore in deeper water, with or without protective grating, have had no known incidence of diving duck entrainment. This could be attributed to the deep water intakes being located beyond the comfortable dive limits of the ducks. On-shore channel water intakes also did not typically entrain ducks. This may be due to several factors including;

- *On-shore intakes in most instances being located at the end of a canal.*
- *The canals usually occurring near active areas of the facilities, such as coal storage areas, business offices, or parking lots, where ducks may be easily frightened away.*
- *The type of duck that frequents the on-shore intakes are usually dabbling ducks (i.e. Mallards, Pintails, etc.) that feed by tipping up and not diving and are, therefore, unlikely to swim into pipe-type intakes.*

5.1 Possible Associated Features

Two other near shore intakes: the Alliant Energy Edgewater facility and the Point Beach Nuclear Generating Station (Point Beach), have similar features to the DEK intake, but did not report having duck entrainment issues. Previously, the Point Beach intake did have significant entrainment occurrences. The intake was remodeled in 2001 and duck entrainment has not been an issue. These installations were scrutinized to determine if the subtle differences in the structures or physical features near the intakes could be a significant factor whether ducks are entrained or not entrained.

5.2 Alliant Energy Edgewater Power Plant
The intake at the Edgewater facility in Sheboygan, Wisconsin, is a similar cone-type intake in approximately 15 feet of water, and is located approximately 1,500 feet off shore. Bill Skalitzky, Senior Environmental Specialist - Alliant Energy, indicated that he was not aware of diving duck entrainment being an issue with the intake. According to Skalitzky, the intakes of Edgewaters Units 3 and 4 are similar to DEK being a cone-shaped, vertical intake, and Unit 5 is somewhat different than the others with the intake being cylindrical but positioned differently. A significant feature that differs greatly between the Edgewater Unit 3s and 4 intakes and the DEK intake is that Units 3 and 4 intakes are elevated approximately 7 to 8 feet above the lake bed. The cone intakes have similar grating, but no other fish or bird deterrent systems are in place on or near the system.

Edgewater also differs in the physical setting of the intakes from that of DEK, where the substratum of the lake bed is reported to be primarily sand, and the shoreline lacks the sheltered "cove" configuration. This could potentially make the area less attractive to ducks because the natural protection of the in-shore area may not provide the same protection. The sand substrate may not be colonized with Zebra mussels, a primary winter food of the diving ducks, to the degree that the clay and rocky substrate near DEK. Therefore, there may naturally be less attractants for migrant ducks to stop over or linger in the off-shore area. Having less ducks in the area likely reduces the risk of duck entrainment. The intake being elevated off the lake bed may also be a critical factor, in that a duck foraging on the natural substrate would have to swim up and over the exterior wall of the structure and purposefully dive back into the structure to continue feeding. In the case of the DEK, a duck foraging on the substrate would have to only move gradually up the exterior riprap of the intake, which may appear to the duck as a continuation of the natural substrate, and then move directly across or into the large open grating on the top of the intake to continue feeding on the interior of the structure. There would be no physical "break" in the elevation or other "obstacle" to surmount to gain entrance to the DEK intake.

5.3 Point Beach Nuclear Generating Station
A second intake scrutinized was Point Beach. The intake structure at Point Beach is similar to the DEK intake in that water is pulled at low velocity into an intake pipe constructed in the bed of Lake Michigan in approximately 15 feet of water and approximately 1,500 to 1,800 feet off shore. STS contacted Dave Michaud (Principal Environmental Scientist - We Energies) and Kjell Johansen (Environmental Coordinator - FPL Group). We Energies (as Wisconsin Electric) had previously owned Point Beach prior to being purchased by the FPL Group in October 2007. According to Michaud, the original intake structure at Point Beach was referred to as a "leaking dam" intake. Essentially, the intake was a ring of large rocks around two circles of H-piles (intakes) with a large pile of rocks in the center. Conduits were inserted in the rocks after they experienced icing problems, and grates and catwalks were installed over the top of the intake mound. Double-crested cormorants, a fish-eating bird, would perch on the rocks surrounding the intake structure and dive into the structure to catch small fish that were using the structure as a protective reef. The cormorants then became entrained. In 2001, the intake structure was remodeled to remove all surface components. Cormorant entrainment no longer occurs. A fish deterrent system is also used at Point Beach

to reduce alewife entrainment and this reduction has served to reduce forage opportunities for the cormorants. Michaud also indicated that the substrate in the area of the intake is sand. Relative to previous discussions on the utilization of Zebra mussels as a dominant winter food of diving ducks, the sand substrate of the area, if not yet fully colonized by Zebra mussels, may not be as attractive to foraging diving ducks and, therefore, less ducks may be in the general area of the intake.

Findings – Comparison of various intake systems found that the Alliant Edgewater Power Plant intake is the most similar to the DEK intake in the area. However, duck entrainment is not a usual occurrence at the Edgewater facility. The major structural difference between the Edgewater and DEK intake cones is the Edgewater cones are elevated approximately 7 to 8 feet off of the lake bed. The DEK intake cones rest on the lake bed. Foraging ducks moving across the lake bed may not be aware that the natural substrate gives way to the intake cones, and continue along into the cones and piping system while feeding on Zebra mussels. The elevated structures may cause the duck to move around the structure to continue feeding, rather than going up and over the top. Differences in the type of substratum occurring at the locations of the two intakes may also have some effect, in that the amount of Zebra mussel colonization of rock and clay substrate in the DEK area may just attract more ducks to the DEK area than other areas along the lake shore. Therefore other facilities may not entrain ducks due to other factors, such as low duck numbers occurring in the area, rather than entrainment being a structural design issue.

6.0 Possible Means of Preventing or Reducing Occurrence of Duck Entrainment

Following the assumption that ducks entering the intake cones to forage is a key factor of the DEK situation, avenues to prevent entry to the cones or decrease attractiveness of the general intake area for foraging were explored. Preventing entrainment would require a physical barrier to eliminate all entry for ducks to the intake cones. To reduce the number of ducks entrained there would need to be a structural and/or behavioral change to deter the ducks from frequenting the intake area or reduce the attraction of the ducks to the intake area. Following is a discussion of possible remediation concepts to prevent or decrease incidental duck entrainment.

Physical Barriers to Prevent Entrainment

- Decrease the current size of the trash grate openings over the intake cones to prevent entrance of the birds.

  Potential Solution - Retrofitting the existing intakes with new grates that would prevent birds from entering the cones would most likely be the most economic structural alternative, in that the old grates could be removed without the need for substantial structural changes or modifications and new grates installed.

  Disadvantage - The grate structure over the intake cones currently has 2-foot square openings. The grate openings were increased in size from the original 12-inch squares due to the formation of frazzle ice. Frazzle ice forms in turbulent water under 32° F, when super-cooled surface water mixes into a thicker layer by forming needle-like ice crystals, or thin, flat circular plates of ice suspended in the water.[10] Frazzle ice appears as liquid "slush" and coats intake grates during cold weather. Frazzle ice has formed rapidly in the shallow off-shore water of the DEK when temperatures fall dramatically. Frazzle ice formation in the past severely restricted the flow of intake cooling water resulting in the shut down of a circulating pump. A pump shut down could jeopardize the ability to maintain proper water levels for the system to stay on line.[2]

To prevent a diving duck from entering the structure, the openings of the grate would need to be reduced to approximately 4-inch square.[11] A grate with small openings needed to prevent ducks from entering the system would quickly become fouled by Zebra mussels and blocked by frazzle ice during the winter. A seasonal change out of the grates from small to large opening also is not feasible because the diving ducks migrate very late in fall, usually just before or during freeze up. Grate change-out would have to wait until after the migration passed, which would require work to be completed after ice formation. The large equipment necessary to complete the work would likely be in winter storage, or unable to reach the work site due to ice formation in harbors. The grates would also have to be changed out before early spring migration, and necessary equipment may once again be unavailable due to ice conditions. The cost of seasonal grate change would be substantial and not justifiable based on the relatively small number of ducks entrained in the intake system on a yearly basis.

- Install a custom-made heated grate system on the intakes to prevent formation of frazzle ice with smaller grate openings that may prevent ducks from entering the intake.

  Potential Solution - The formation of frazzle ice and accompanying risk of reduced water supply to power generation system would not occur. The grate openings may be smaller, which could deter duck entrance into the intakes.

  Disadvantage - The openings in the grate would likely be fouled easily by Zebra mussels, unless the grate is heated to the point of preventing mussel colonization. Studies of heat tolerance of Zebra mussels have found that a chronic thermal of 34°C (93.2F) for 6 to 26 hours was sufficient to induce nearly 100% mortality.[12] However, this temperature is related to neutralizing Zebra mussel transfer through bilge water. Correspondence with Hulsinger Electric, a manufacturer of heated intake grates, has found that Zebra mussel attachment to intake grate surfaces is lessened, but not totally prevented, at a heated bar temperature of 17°C (62.6°F).[13] A separate antifouling system could potentially be combined with the heated grate, such as a chlorination system that emits chlorine into the water surrounding the intake to kill Zebra mussel larvae. However, a chlorination system would indiscriminately affect all life around the intake, including to some degree the ducks, and may also

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[10] Underwater Consultants, Inc. webpage, Frazzle Ice - definition, January 16, 2008.

[11] Howe, Robert, University of Wisconsin-Green Bay, personnel communication, January 15, 2008.

[12] McMahon RF, et al. Studies of heat tolerance of Zebra mussels: Effects of temperature acclimation and chronic exposure to lethal temperatures, US Army Corps of Engineers Technical Report EL-95-9. 1995.

[13] Hulsinger, Mike, Hulsinger Electric, Inc. personal communication, March 5, 2008.

enhance corrosion of metal components. Continual chlorination of the circulating water system would be very expensive and would add residual hypochlorite to the lake.

Operation of the heated grates would incur associated electrical costs. The heated grates, although advantageous in the winter, would likely need to be operated throughout the year to prevent mussel colonization at a substantial cost to the user.

The grates would require some basic structural modification to the intakes and installation of electrical components to power the grate, also at a cost to the user.

- Removable screen

  Potential Solution - Install a suspended net or screen around the entire inlet structure to prevent access to the intake area. Having only a small opening above the intake would likely reduce the number of birds swimming laterally into the intake.

  Disadvantage - The net would need to be suspended from the lake bed to the surface. However, no visible indicators of the presence of the intake structures, such as net floats, containment booms, or any floating or stationary object can appear on the water surface at the location of the intake due to potential security risks to the power plant. Suspended nets would also need to be removed after fall migration at or during winter freeze-up, which would present problems with equipment due to ice formation. The nets would also need to be deployed before spring migration occurs when required equipment would still be iced-in in harbors and not available.

- Relocating the intake structure

  Potential Solution - Relocating the intake structure into deeper water would reduce the risk of duck entrainment in that the ducks frequent shallower waters where food is more easily obtained at comfortable diving depths. Deep water would not be as attractive to the ducks for feeding or loafing. A deep water intake would also not be affected by frazzle ice.

  Disadvantage - Relocation of the intake would be considered a substantial modification to the operation of DEK and very costly. The actual construction of a new intake to reach deeper water would be a multi-million dollar project, and not justifiable based on the relatively small number of ducks entrained in the intake system on a yearly basis.

Behavioral Deterrents

- Use of predator mannequins

  Potential Solution - Use of predator mannequins or decoys that pose a threat and discourage birds from frequenting the intake area could be a low cost solution that would work for short periods of time during spring and fall migration.

Disadvantage - Diving ducks have limited predators, such as hunters, large fish, or large raptor.[11] A predator mannequin would need to be located subsurface to prevent any surface marking of the intake location, which eliminates stationary boats with hunters or large bird mannequins. Birds also become complacent with stationary mannequins and the mannequins would quickly lose effectiveness. Mannequins, such as a suspended large fish, would likely become covered in algae in a short time and lose effectiveness, and then would require frequent routine maintenance.

- Alarm or fright deterrents (hazing or flushing methods)

  Potential Solution - Research is ongoing to determine which method of hazing, or frightening waterfowl to discourage use of the area, is more effective due to the large number of industrial and municipal wastewater storage or treatment lagoons that must repel waterfowl. There are some sight and sound stimulus (noise blasters, motion detectors, etc. that have some degree of effectiveness.[14] A hazing method is being devised to detect birds flying into wastewater ponds and respond by producing a variety of different noises to scare the birds away. The variety of the noise is thought to decrease complacency of the birds to the stimulus.[15]

  Disadvantage - Most hazing devices that use sound, such as a bird cannon that periodically emits a loud noise, need to operate in open air, and to be most effective would have to be located on a float near the intake to scare birds away from the general area. There are models available that float in the water with only a small portion of the device extending above the surface.[16] As nothing can mark the location of the intake due to security concerns, a sound emitting hazing device is not a feasible solution. Also, employing a general hazing device may cause enough of a general detraction in the open water area off shore of DEK that what now may be an important rest and feeding stop over on the migration route is avoided by waterfowl. Hazing may actually put greater numbers of waterfowl into peril by being denied access to a protected off-shore area with an ample food supply during seasonal migration, which may nullify the importance of the loss of a few individuals to entrainment. The importance of the off-shore open water area by DEK is unknown and more research would need to be completed to determine migratory significance of the area.

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[14] Boag, D.A. and V. Lewin, 1980, Effectiveness of Three Waterfowl Deterrents on Natural and Polluted Ponds, Journal of Wildlife Management, 44:145-154.

[15] Ronconi, R.A., Cassady, C., 2006, Efficacy of a Radar-activated, On-demand System for Deterring Waterfowl for Oil Sands Tailings Ponds, Journal of Applied Ecology.

[16] Whisson, D. and Takekawa, J. Testing the Effectiveness of an Aquatic Hazing Device on Waterbirds in San Francisco Bay, California, Report Prepared for California Department of Fish and Game, Office of Oil Spill Prevention and Response, May 1998.

- Subsurface acoustics

  Potential Solution - Acoustic fish deterrent systems are known to be effective at repelling selected species of fish. An acoustic system might be customized to emit sound at decibels that would repel the known fish in the area and, therefore, remove the food attractant for fish eating ducks from the intake area. The sound may or may not have an effect on the comfort level of ducks beneath the water surface.

  Disadvantage - Repelling fish will not affect diving ducks that forage on Zebra mussels, plants, and other benthos, such as lesser Scaup, Buffleheads and Goldeneye ducks, which are the species of duck that have been the most common victims of entrainment. Diving ducks are also known to have poor hearing capability and if affected by underwater sound, would simply pop to the surface rather than leave the area.[12] Acoustic repellent systems are very expensive, requiring structural support modification at the intakes and significant on-shore equipment support. Michaud related to STS that installation of the acoustic repellant system specifically targeting alewives cost more than $500,000 in 2002. An acoustic system installed today would likely exceed a cost of $500,000.

Combined Structural Modifications and Behavioral Deterrents

- Modification of intake to eliminate food source

  Potential Solution - Modifications to the intake structures could be made to reduce the presence of Zebra mussels within the interior, where it is hypothesized the birds are following the food source (mussels) too far into the system and become entrained. To remove the food source without additional implications of chemical treatment such as chlorination, the intake structures could potentially be lined with copper, which studies have indicated as unfavorable for colonization by Zebra mussels.[5] Holdridge indicated that the City of Escanaba, Michigan, lined the City's raw water intake structure with copper in an effort to reduce colonization of Zebra mussels. He observed the copper-lined structure over a multiple year time period since installation and stated that, in his opinion, the density of Zebra mussels on the structure was much less than surrounding substrates. He attributed the lack of colonization to the rapid oxidation of copper and the subsequent oxidation flaking off and taking any attached Zebra mussels with it. Another method of decreasing colonization of the intake by Zebra mussels has been to slightly increase the flow velocity of the intake water to greater than 1.5 m/sec^{-1} or 0.05 fps.[5] Currently, the intake velocity is reported to be less than 1 fps, and Zebra mussels are known to be present within the DEK intake. However, according to Holdridge the Zebra mussels are attached to algae that bonds to the interior of the pipe, which may explain why the velocity of the water is not directly influencing Zebra mussel colonization.

  Disadvantage - Retrofitting the existing intake cones with copper would require a significant construction effort and costs, and the intakes would most likely still become coated with algae, which in turn may be able to support Zebra mussel colonies on substrate even in increased flow velocities.

- Modification of intake structure to change perception to ducks

  Potential Solution - It is hypothesized that the foraging ducks move along the lake bed eating Zebra mussels, and do not recognize that the intake cone (raised above the lake bed approximately 1 foot) is different from other areas of the lake bed, and they continue feeding while moving into the structure and become entrained. A similar intake structure at the Edgewood Power Plant is elevated 7 to 8 feet above the lake bed, and duck entrainment has not occurred. By raising the intake cones off the lake bed by at least 7 feet, it may represent to the duck that the intake structure is not a part of the natural lake bed, causing it to veer around or away from the structure to continue foraging on the natural lake bed. Installing a rigid vertical screen around the outer edge of the intake cones may discourage direct lateral movement of the ducks from natural substrate into the cones.

  Disadvantage - The depth of water at the intake structure is currently estimated at approximately 12 feet. Raising the intake cones 7 to 8 feet off of the bottom would put the cones within 5 feet of the water surface, where they could be impacted by boat traffic or ice movement. Installation of a rigid screen extending from the lake bed around the intake cones may affect the formation of frazzle ice in the winter, and would also extend close to the surface and the possibility of winter storms damaging any lake bed structure is very likely. However, it is unknown whether the intake cones would need to be raised as high as 7 to 8 feet, or something with less elevation, such as 4 feet, would suffice in demonstrating to the ducks that the structure is no longer the natural lake bed. More study would have to be completed to determine if raising the intake cones could be the solution, to what extent they would have to be raised, and the estimated cost of intake renovation.

7.0 Conclusion

The investigation has found the following:

- *The area off shore of the DEK is attractive to migrating waterfowl. A concentration of migrating diving ducks in the general area of DEK for potentially longer time durations may increase the potential for duck entrainment.*

- *It may be generally surmised that the ducks are becoming entrained because they are feeding within the intake cones, and not being drawn into the intake structure by swimming in the general area of the intakes.*

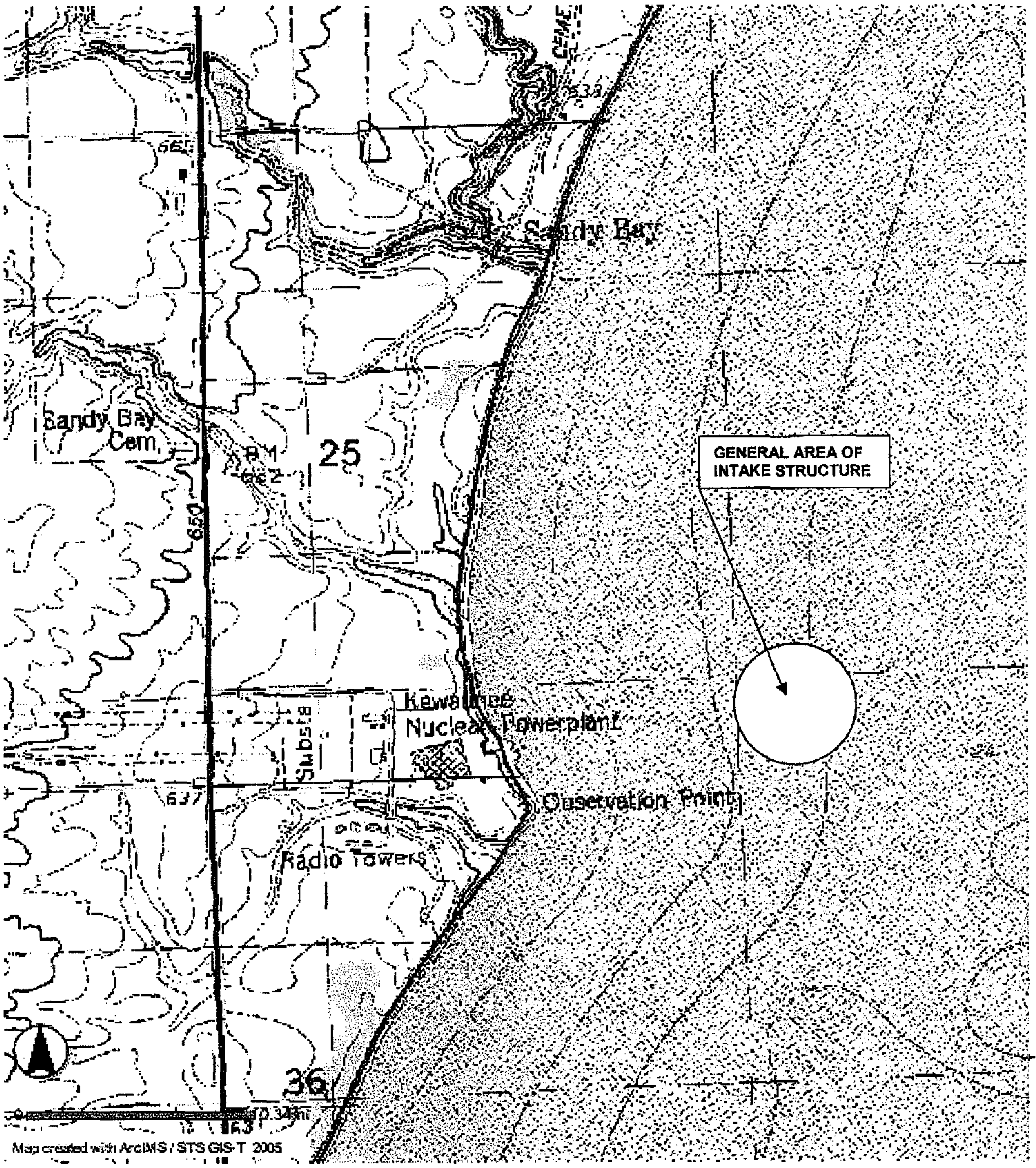
- *Entrainment of diving ducks in water systems along the west shore of Lake Michigan is not a common problem for the facilities contacted by STS. Intake systems that are located further off-shore in deeper water, with or without protective grating, have had no known incidence of diving duck entrainment. This could be attributed to deep water intakes located beyond the comfortable dive limits of the ducks. On-shore canal water intakes also did not typically entrain ducks. This may be due to several factors including:*

1. *On-shore intakes in most instances located at the end of a canal.*
2. *The canals usually occur near an active zone of the facility, in most cases near coal storage areas, business offices, or parking lots, where ducks may be easily frightened away.*
3. *The type of duck that frequents the intake channels are usually dabbling ducks (i.e. mallards, pintails, etc.) that feed by tipping up and not diving and are, therefore, unlikely to swim into pipe-type intakes.*

- *A comparison of various intake systems found that the Alliant Edgewater Power Plant intake is the most similar to the DEK intake in the area. However, duck entrainment is not a usual occurrence at the Edgewater facility. The major structural difference between the Edgewater and DEK intake cones is that the Edgewater cones are elevated approximately 7 to 8 feet off the lake bed. The DEK intake cones rest on the lake bed. Foraging ducks moving across the lake bed may not be aware that the natural substrate gives way to the intake cones, and continue along into the cones and piping system while feeding on Zebra mussels. The elevated structures may cause the ducks to move around the structure to continue feeding, rather than going up and over the top. Differences in the type of substratum between the two intakes may also have some effect, in that the amount of Zebra mussel colonization on rock and clay substrate in the DEK area may result in more ducks in the DEK area than other areas along the lake shore. Therefore, other facilities may not entrain ducks due to other factors, such as low duck numbers occurring in the area, rather than entrainment being a structural design issue.*

Review of possible solutions that may be applied to prevent or reduce duck entrainment found that each had disadvantages, whether due to lake conditions such as limited water depth or forces of ice, or economic limitations (i.e. the solution for the problem would not be economically practical based on the small number of duck fatalities occurring on a yearly basis). To put the entrainment issue into perspective, the number of ducks sporadically found entrained during the spring and fall migration of 2006 and 2007 usually did not exceed daily waterfowl hunting bag limits allowed a single hunter in most of the states located along the traditional duck migratory flyway.

Attachments:
    Figure 1 - Site Location Diagram
    Dominion Energy Kewaunee Duck Log



Map created with ArcIMS / STS GIS-T 2005

STS | AECOM

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LOCATION DIAGRAM
DOMINION ENERGY KEWAUNEE
TOWN OF CARLTON, KEWAUNEE COUNTY, WI

Drawn:	JJT 02/11/2008
Checked:	
Approved:	SJS 02/12-2008
PROJECT NUMBER	200705952
FIGURE NUMBER	1

Kewaunee Power Station

Duck Log

Date	Number of Ducks	Other Birds	Species
02/23/2006	16		Mergansers
02/27/2006	4		2 Barrows Goldeneyes, 2 Common Goldeneyes.
03/07/2006	2		1 Barrows Goldeneyes, 1 Common Goldeneyes.
03/08/2006	0*		It was reported to the ECC that there as a duck in the forebay, but it was determined that the bird was a pigeon.

22

11/09/2006	3		3 buffleheads. 2 juvenile males and 1 female
11/15/2006	5		5 buffleheads. 4 males (2 juvenile and 2 adults) and 1 female.
11/29/2006	1		Bufflehead.
12/06/2006	2		Bufflehead.

11

2007

02/19/2007	1		Bufflehead.(drake)
03/11/2007	3		1 Bufflehead(drake), 2 Bluebill (drake).
03/22/2007	3		1 Goldeneye (drake), 2 Bluebill (drake).
07/03/2007		1	Woodcock or snipe (shorebird) on top of Aux. Building
08/26/2007		1	Peregrine Falcon in heating boiler stack (juvenile)
09/19/2007		1	Pheasant flew into building
12/15/2007	6		4 Goldeneye, 2 Buffleheads.

13 3

01/07/2008

Table 1

Facility and Contact	Intake Description	Depth water at Intake	Substrate	Occurrence of Duck Entrainment
FPL Group - Point Beach Nuclear Generating Station Kjell Johansen - FPL Group, Environmental Coordinator Dave Michaud - We Energies (former owner), Principal Environmental Scientist	Previous intake was a "leaking dam" of rock piled around a below surface intake structure. The rock dam extended approximately 2 feet above the water surface. The intake was dismantled and reconstructed in order to remove the above surface rocks that cormorants had been using as resting perches while diving into the intake to pursue fish, resulting in several entrainment fatalities. The remodeled intake is now entirely below the water surface and cormorant entrainment is no longer occurring. An acoustic fish deterrent device was installed at the intake to keep fish away from the area. The acoustic deterrent seems to be effective and may also be a factor in eliminating incidental bird entrainment. Zebra mussels are periodically cleaned off the structure.	Approx. 15 to 18 feet	Sand	Cormorants had been previously entrained when previous system in use
We Energies - Port Washington Power Plant Dave Michaud - We Energies, Principal Environmental Scientist	Intake structure on shore with a 1,100-foot feeder canal from Lake Michigan. Canal is situated near the coal docks. Discharge water from the plant is to the harbor. Activity in area due to coal dock. Fishermen are allowed access to the canal in pursuit of large fish that come into the canal following the warm water, which roughly affects one-third of the distance of the canal. Dabbling ducks are observed occasionally on the canal, but have not entrained the ducks in the system.	Shallow	n/a	None known
We Energies - Valley Power Plant Milwaukee Dave Michaud - We Energies, Principal Environmental Scientist	Power plant has a once-through circulating system that uses only small volumes of water from an on-shore intake in the Milwaukee River.	Shallow	n/a	None known
We Energies - Pleasant Prairie Power Plant Dave Michaud - We Energies, Principal Environmental Scientist	Closed cycle cooling system with only a small intake in Lake Michigan to feed make-up water into the system. The intake structure is very small at a depth of approximately 20 feet below the surface.	20 feet	Unknown	None known
We Energies - Oak Creek Power Plant Dave Michaud - We Energies, Principal Environmental Scientist	Current cooling system uses an on-shore intake at the end of a canal. A new intake structure is being constructed in conjunction with power plant expansion. The new intake will be an array of several screened intakes that feed water into a 26-foot diameter tunnel extending approximately 9,000 feet off shore in water depths of 43 to 45 feet.	Existing canal shallow	Unknown	None known
Wisconsin Public Service - Pulliam Power Plant Rick Moser, Integrys, Environmental Consultant	On-shore intake from the Fox River at Green Bay interface. Intake is at water surface. Ducks and other shorebirds congregate in the area.	Shallow	N/A	None known

Table 1

Facility and Contact	Intake Description	Depth water at intake	Substrate	Occurrence of Duck Entrainment
Alliant Energy - Edgewater Power Plant Bill Skalitzky, Senior Environmental Specialist	Intake consists of three structures. Units 3 and 4 intakes are cones leading to an intake pipe in the lake bed. Cones are elevated above the lake bed approximately 7 to 8 feet. Unit 5 intake is cylindrical, but positioned differently. Zebra mussels are cleaned periodically out of Unit 5 intake. Zebra mussels are not prevalent in Units 3 and 4 intakes.	15 feet	Sand	None known
Green Bay Water Utility - Lake Michigan Raw Water Intake near Kewaunee Brian Powell, P.E.	Two raw-water intakes at approximately 3,000 feet and 6,000 feet off shore. The 6,000-foot intake is usually operated, as the 3,000-foot intake has more issues with undesirable water quality. Intakes do not have any type of screening. Periodically inspected for Zebra mussels.	3,000-foot intake pipe at approx. 30-foot depth, the 6,000-foot intake pipe at 60-foot depth	Unknown	No duck entrainment. Occasional large fish usually captured unharmed and released
Manitowoc Public Utilities - Lake Michigan Raw Water Intake off shore of Manitowoc Nilaksh Kothari, P.E.	Two raw-water intakes, one in deep water approximately 1 mile off shore, one near the shore. Near-shore intake is covered with rock.	Deep intake at approx. 40 feet	Unknown	No duck entrainment

From: Theodore L Maloney/Generation/4/Dom
To: Jeanne M Ferris/Generation/4/Dom@VANCPOWER, Richard J Gallagher/Generation/6/Dom@VANCPOWER

Date: Wednesday, May 27, 2009 11:17AM
Subject: NRC Requested Documents

USFWS Migratory Bird Analysis

ISFSI Wetlands area

Remaining Wetlands	0.37 acres
Removed Wetlands	0.03 acres

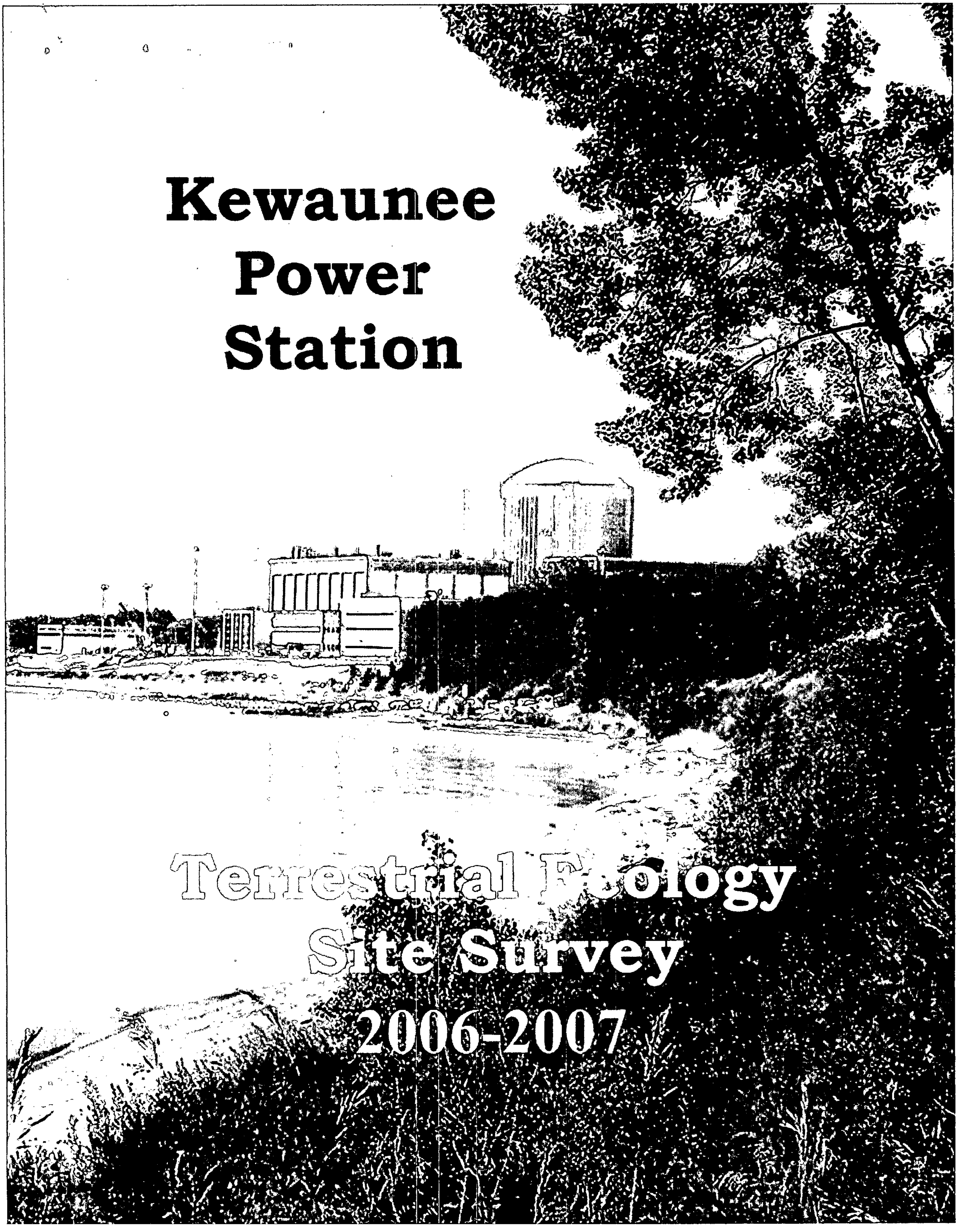
FYI.

Ted Maloney
Senior Environmental Compliance Coordinator
Kewaunee Power Station
Office: 920-388-8863
Fax: 920-388-8333
Pager: 920-305-0368
Theodore.L.Maloney@dom.com

Attachments:

Migratory-Bird-Taking-Study-STS-(7-28-09).pdf

Kewaunee Power Station



Terrestrial Ecology Site Survey

2006-2007

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1.0 PURPOSE

A comprehensive site survey has been performed in preparation for the submittal of a License Renewal Application for the Kewaunee Power Station, located in the southeastern corner of the town of Carlton, Kewaunee County, Wisconsin. The main objectives of this site survey were to:

- Ascertain terrestrial habitat types on the site;
- Determine what plant and animal species are found on the site; and
- To the extent possible, determine the presence or absence of federally- and state-listed threatened and endangered (T&E) species.

An additional objective was to, while performing the ecological survey, examine the potential for the presence of historic or archaeological resources on site.

This report covers: the Spring site survey, performed May 8-18, 2006; the Summer survey, performed June 12-15 and July 12-19, 2006; the Fall survey, performed September 26-October 5, 2006; and the Winter survey, performed January 4-11, 2007.

The individual performing this site survey was Richard J. Gallagher, B.A., Biology, and M.S., Natural Resource Administration and Management. Although the author does not have specific academic background in historic and archaeological resources, he does have prior experience in this area, having performed similar research at the Millstone Power Station site in Waterford, Connecticut as part of its license renewal process. During the course of this survey, he also consulted with the Kewaunee County Historical Society, and visited the Society's Research Center in Algoma.

Numerous resources were used as identification aids and references during the survey. They include, among others:

- National Geographic Society, Field Guide to the Birds of North America, Third Edition, 1999; Mary B. Dickinson, Editor
- Newcomb's Wildflower Guide, 1977, by Lawrence Newcomb
- Door County's Wildflowers, 2005, by Frances M. Burton and Aurelia M. Stampp
- MIT Press, North American Trees, 1976, by Richard J. Preston, Jr.

- The Peterson Field Guide Series, A Field Guide to the Mammals, Third Edition, 1976, by William H. Burt and Richard P. Grossenheider
- The Peterson Field Guide Series, A Field Guide to Animal Tracks, Second Edition, 1975, by Olaus J. Murie
- Wisconsin Department of Natural Resources, Checklist of Wisconsin Birds, Great Wisconsin Birding and Nature Trail, undated, accessed on March 6, 2006 at

  http://www.dnr.state.wi.us/org/land/er/publications/GWBNT/checklist.pdf
- Wisconsin Department of Natural Resources—Division of Forestry and the Bureau of Endangered Resources, Threatened and Endangered Species in Forests of Wisconsin, 2000, accessed on March 6, 2006 at

  http://dnr.wi.gov/org/land/forestry/publications/endangered/PDF/WIFieldGuide.pdf
- Wisconsin Department of Natural Resources, Wisconsin Endangered and Threatened Species Laws & List, PUBL-ER-001, 2004, accessed on March 6, 2006 at

  http://dnr.wi.gov/org/land/er/working_list/taxalists/ETListCompletePub04.pdf
- Wisconsin Department of Natural Resources, Wisconsin Wildlife Primer—Wildlife Habits and Habitat, undated, accessed on March 6, 2006 at

  http://dnr.wi.gov/org/land/wildlife/publ/wildland.htm
- Wisconsin Department of Natural Resources, Wisconsin State Threatened and Endangered Species Fact Sheets, undated, accessed on March 7, 2006 at

  http://www.dnr.state.wi.us/org/land/er/working_list/taxalists/TandE.asp
- Wisconsin Department of Natural Resources, Wisconsin's Federally Listed Species, undated, accessed on July 25, 2006 at

  http://www.dnr.state.wi.us/org/land/er/working_list/taxalists/fed_listed.asp
- Smithsonian National Museum of Natural History, Field Guide to North American Mammals, undated, accessed on April 20, 2006 at

  http://baird.si.edu/mammals_arcims/viewer.htm?Title=North%20American%20Mammals

2.0 BACKGROUND

Kewaunee Power Station (KPS) is located in the southeastern corner of the Town of Carlton, Kewaunee County, Wisconsin. The Station's 908-acre site is roughly bisected by Wisconsin State Route 42 (Figure 1). St. John's Lutheran Cemetery, also known as Sandy Bay Cemetery, which occupies 1.13 acres within the site, is owned and maintained by the Town of Carlton[1].

Prior to construction of the Station, the site was used primarily for farming. Dominion continues to lease approximately 407 acres to area farmers, most of which is located to the west of Route 42[2]. This agricultural land provides different habitat for the area's wildlife, and it was included in this survey.

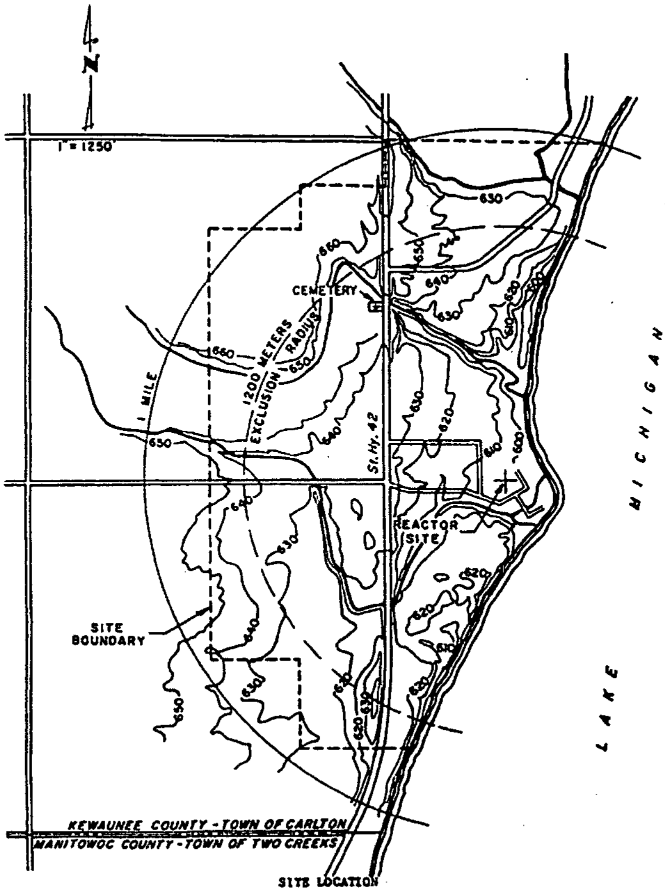
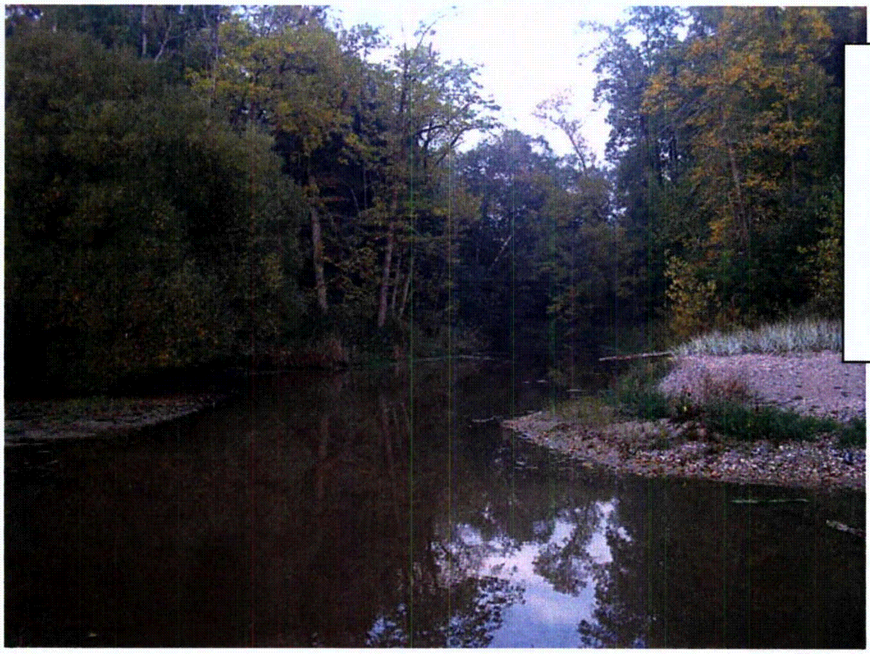


Figure 1—KPS Site, showing site boundary

The overall site slopes gradually from elevations approximately 100 feet above the level of Lake Michigan, eastward toward the lake. On the northern and southern ends of the site, steep bluffs drop quickly toward the shore of the lake, whereas the central portion of the site, which includes the Power Station itself, has a much more gradual slope[3].

The level of the lake itself fluctuates from decade to decade, varying from approximately 576 feet above sea level in 1964, to approximately 582 feet above sea level in 1987[4]. As a result, the site goes through periods of cliff erosion and narrow beaches during high water years, and other times when cliff erosion is not prevalent, and the beach is more expansive. This consequently results in fluctuations in the availability of nesting habitat for beach-nesting birds. In 2006, lake level stood at approximately 577 feet[5].

Surface water drainage on the site is via three main stream systems. At the northern edge of the site, Sandy Bay Creek empties into Lake Michigan, approximately 0.8 mile north of the plant. This creek, along with its tributary, Fischer Creek, provides approximately 36 acres of woodland/riverine habitat for a variety of flora and fauna[6]. This area also contains a substantial part of the site's history, which will be discussed later.



Sandy Bay Creek empties out into Lake Michigan near the northern end of the KPS property.

An unnamed intermittent stream that drains into the lake approximately ¼ mile north of the plant, and another approximately ¼ mile south of the plant, drain most of the rest of the site. Together, these two streams add an additional 60 acres of woodland, early succession field and streamside vegetation[7].

Approximately ½ mile south of the plant lies the Joe Krofta Memorial Forest, a monument to the former owner of that part of the site. The 15-acre forest[8], formerly known as the Kewaunee School Forest, was dedicated in 1987 to the former owner of that part of the property, who planted and cared for the forest[9]. It was used by Kewaunee schools as an outdoor classroom, but was closed due to security concerns. Surrounding this forest is an area of approximately 42 acres[10], some of which was maintained for several years as a restored prairie. It presently exists in various stages of ecological succession.

Finally, near the southern edge of the property, there is a drainage ditch that drains storm water from a small portion of the site. A 1-2 acre forested area surrounds this drainage ditch.

Overall, although largely open fields, much of them under cultivation, the site contains a variety of scattered habitats, which create "edge" that is potentially conducive to wildlife. This survey was performed in an effort to ensure all habitat types were included, and to ascertain species present.

The site was divided into eight areas, as shown in Figure 2, to facilitate description of habitats present.

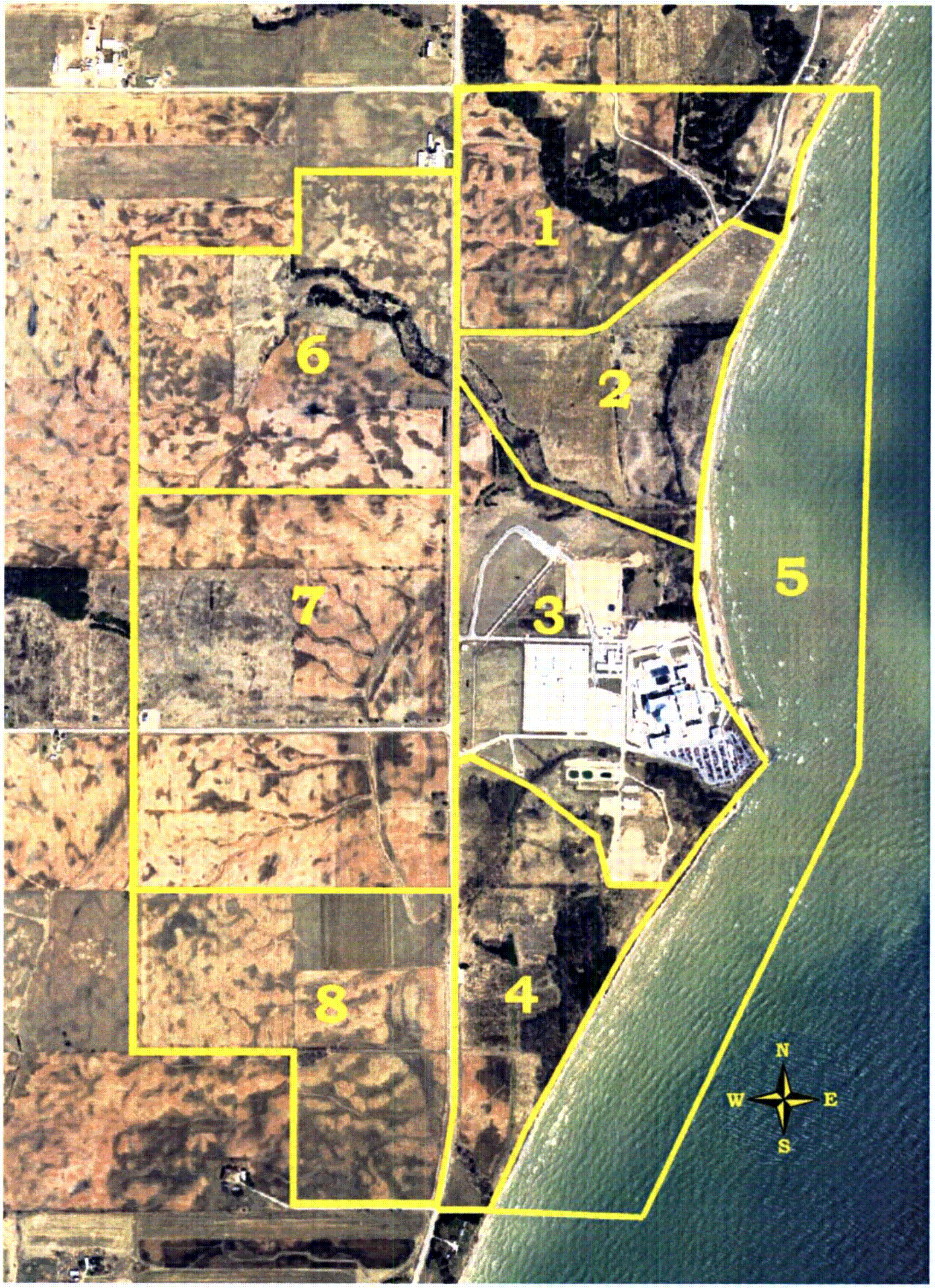


Figure 2—Aerial view of KPS, showing site boundary and the eight study areas described below.

3.0 HABITAT AND WILDLIFE

3.1 AREA 1: SANDY BAY CREEK/FISCHER CREEK AND SURROUNDINGS

Area 1 is bounded to the north by the site property line; to the west by State Route 42; to the east by the cliff above the beach; and to the south by Lakeview Drive and the open field south of Sandy Bay Creek downstream of the bridge on Lakeview Drive.

Sandy Bay Creek, with its tributary, Fischer Creek, drains the northeast corner of the Kewaunee site into Lake Michigan approximately 0.8 miles north of the plant. The drainage basin includes approximately 100 acres of Dominion property, most of which is under lease to local farmers. Approximately 36 acres of land, most of it directly adjacent to the two creeks, is either forested or in fields in various stages of succession.

During performance of the May survey, both streams were flowing. Following rainstorms during the May survey, the streams were quite high. In June, flow in Sandy Bay Creek was low, and Fischer Creek exhibited very low flow. By July, Fischer Creek had stopped flowing, and had only intermittent, shallow pools. Flow in Sandy Bay Creek in July was minimal. During the Fall survey, stream flow followed the pattern found during the summer: Fischer Creek was not flowing, and Sandy Bay Creek had minimal flow. In the Winter, due to an unusually warm and rainy December and early January, flow in both streams was equal to or slightly greater than that of the Spring.

The stream system empties into Lake Michigan in an area of steep sand dunes and, at present, a sandy beach. The beach itself, and the adjacent waters of Lake Michigan, comprise a portion of Area 5, described below, and are not included in this discussion of Area 1.

Downstream from the confluence of Sandy Bay Creek and Fischer Creek, the predominant trees are quaking aspen (*Populus tremuloides*), northern white cedar (*Thuja occidentalis*), eastern cottonwood (*Populus deltoides*), black willow (*Salix nigra*) and paper birch (*Betula papyrifera*). Other trees present include green ash (*Fraxinus pennsylvanica*) and small numbers of American basswood (*Tilia americana*) and black hawthorn (*Crataegus* sp.). The red osier dogwood (*Cornus stolonifera*), an important source of food and cover for numerous species of birds and mammals, is a prominent shrub in this area. The area also contains several Russian-olive (*Elaeagnus angustifolia*), an invasive species typically found in previously disturbed areas. During the June survey, both red osier dogwood and Russian olive were flowering, and in July, both were in berries. By Fall, most dogwood berries were gone, but Russian olive berries remained. Groundcover includes, among other things, cow parsnip (*Heracleum* *lanatum*), common blue violet (*Viola sororia*), dandelions (*Taraxacum officinale*), common burdock (*Arctium minus*), horsetails (*Equisetum sp.)*, white campion (*Silene latifolia*), and Virginia waterleaf (*Hydrophyllum virginianum*).

Upstream of the confluence of the two creeks, Sandy Bay Creek winds in a northerly direction. Steep banks that rise 20 to 30 feet on either side of the stream characterize the area. Northern white cedar is the predominant tree, followed by quaking aspen, green ash and paper birch. Other species present along the banks going down to the stream include American basswood and black hawthorn. Adjacent to a leased field to the east of the stream, a large sweet birch (*Betula lenta*) and sugar maple (*Acer saccharum*) are found, in addition to the aforementioned dominant trees.

An area to the west of Sandy Bay Creek opens into a small area of early succession, dominated by grasses and white sweet-clover (*Melilotus alba*), but interspersed with thickets of red osier dogwood and Russian olive. The eastern border of this area has a large number of medium-sized northern white cedar. This area is bordered to the west by a grove of spruce and balsam fir trees, which separates the open area from a cultivated field. A network of deer trails, with fresh sign, is evident: not surprising, considering the abundance of dogwood and northern white cedar.

Fischer Creek drains the area to the west and northwest of the confluence of the two creeks. This creek also has steep sides in some areas and, based on its appearance and known history, was likely once a larger stream than it is today. On the Dominion portion of this stream, there are numerous areas where the stream banks are much more gradual, allowing reasonably easy access to the streamside.

Vegetation is similar to that of Sandy Bay Creek, with white cedar predominating, followed by quaking aspen, paper (*Betula papyrifera*) and yellow birch (*B. alleghaniensis*), green ash, eastern cottonwood and black willow. Sugar maples, American beech (*Fagus grandifolia*), sweet birch, and basswood are also present. Scattered areas of red osier dogwood are found throughout the area.

Groundcover along Fischer creek and in the adjacent forest and fields includes: various ferns, common blue violet (*Viola sororia*), downy yellow forest violet (*Viola pubescens*), wild leek (*Allium trioccum*), common burdock (*Arctium minus*), horsetails (*Equisetum sp.*), dandelion (*Taraxacum officinale*), Queen Anne's lace (*Daucus carota*), jewelweed (*Impatiens capensis*), marsh marigold (*Caltha palustris*), dame's rocket (*Hesperis matronalis*), white campion, Virginia waterleaf, ox-eye daisy (*Leucanthemum vulgare*), orange hawkweed (*Hieracium aurantiacum*), red clover (*Trifolium pratense*), day lily (*Hemerocallis fulva),* May apple (*Podophyllum peltatum*) common fleabane (*Erigeron philadelphicus*), bird's-foot trefoil (*Lotus corniculatus*), Canada thistle (*Cirsium arvense*), butter-and-eggs (*Linaria vulgaris*), and field pennycress (*Thlaspi arvense*). In the fall, the dominant flowering ground cover vegetation consisted of goldenrod (*Solidago sp.*) and various asters (*Aster sp.*), primarily Calico Aster (*Aster lateriflorus*) and New England Aster (*Aster novae-angliae*). In one open field, Maximilian's Sunflower (*Helianthus maximilianii*) was also present.

The Fischer Creek watershed includes adjacent land that is leased to farmers, creating edge where, after crops begin to grow, some opportunities for edge habitat exist. The species able to take advantage of this edge will vary from year to year, depending on the crop. At one point in particular, to the north of the stream, there is an area of several acres between land currently under cultivation and the stream, which contains numerous stages of ecological succession. As a result, the area contains a diversity of wildlife, particularly birds. The red osier dogwood is a prevalent shrub of this area, as well as other open areas in the vicinity of Fischer Creek. Other species present include small white cedar, basswood, beech and ash trees.

During the spring survey, no mammals were observed directly; however, signs of mammal presence were abundant. The area is rife with whitetail deer (*Odocoileus virginianus*) trails with fresh sign, including scat and tracks. Raccoon (*Procyon lotor*) tracks were abundant streamside. Numerous animal burrows were observed. The scat of predators, including that of a coyote (*Canis latrans*), was observed. During a previous site visit, the skull of a red fox (*Vulpes vulpes*) was seen, and site personnel have reported seeing badgers (*Taxidea taxus*) in this area.

In the summer, direct observations were made in this area of the following mammals: whitetail deer, raccoon, fox squirrel (*Sciurus niger*), red squirrel (*Tamiasciurus hudsonicus*), and chipmunk (*Tamias striatus*). In the fall, a raccoon, chipmunk, and red squirrel were observed. During the Winter survey, coyotes could be heard calling from nearby, and numerous deer and eastern cottontail (*Sylvilagus floridanus*) were observed. Raccoon and opossum (*Didelphus marsupialis*) tracks were also present.

A large number and diversity of birds were identified in this area. Table 1 below lists the birds observed in Area 1.

No reptiles or amphibians were observed during the spring survey. In the summer and fall, American toads (*Bufo americanus*) were observed. Certainly, habitat exists for additional amphibian species, but none were observed, including tadpoles or egg masses.

Butterflies seen in this area in the spring included the cabbage white *(Pieris rapae)* and monarch *(Danaus plexippus).* In the summer, this list expanded to include pearl crescent (*Phyciodes tharos*), great spangled fritillary (*Speyeria cybele*), black swallowtail (*Papilio polyxenes*), and clouded sulfur (*colias philodice*). By the fall, the population was lower, but included Eastern tailed-blue (*Cupido comyntas*), cabbage white, clouded sulfur, and red admiral (*Vanessa atalanta*).

It is important to note that, because the area of northern Lake Michigan is a potential habitat for the federally- and state-threatened dwarf lake iris (*Iris lacustris*), the federally- and state-threatened dune thistle (*Cirsium pitcheri*) and the state-threatened gastropod cherrystone drop (*Hendersonia occulta*), a particular effort was made to determine the presence or absence of these species. Because of an established association between white cedar forests and dwarf lake iris, this area was scanned carefully, and the spring survey was timed not only for the bird migration, but also to coincide with the blooming season for the dwarf lake iris. No specimens of any of these three species were observed.

Table 1: Birds Identified in Area 1, the Sandy Bay Creek/Fischer Creek Area

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Red-winged Blackbird	*Agelaius phoeniceus*	X	X		
Mallard	*Anas platyrhynchos*		X		X
Gadwall	*Anas strepera*		X		
Great Blue Heron	*Ardea herodias*	X	X		
Cedar Waxwing	*Bombycilla cedrorum*		X		
Canada Goose	*Branta canadensis*			X	X
Red-tailed Hawk	*Buteo jamaicensis*		X		
Northern Cardinal	*Cardinalis cardinalis*	X	X		
Pine Siskin	*Carduelis pinus*	X			
American Goldfinch	*Carduelis tristus*	X	X	X	X
Turkey Vulture	*Cathartes aura*	X			
Veery	*Catharus fuscescens*	X			
Hermit Thrush	*Catharus guttatus*	X		X	
Brown Creeper	*Certhia americana*			X	
Belted Kingfisher	*Ceryle alcyon*	X	X		
Chimney Swift	*Chaetura pelagica*		X	X	
Northern Flicker	*Colaptes auratus*		X	X	
Eastern Wood-Pewee	*Contopus cooperi*		X		
American Crow	*Corvus brachyrhynchos*	X	X	X	X
Blue Jay	*Cyanocitta cristata*	X	X	X	X
Yellow-rumped Warbler	*Dendroica coronata*	X		X	

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Magnolia Warbler	*Dendroica magnolia*	X			
Palm Warbler	*Dendroica palmarum*	X			
Chestnut-sided Warbler	*Dendroica pensylvanica*	X			
Gray Catbird	*Dumetella carolinensis*	X	X	X	
Least Flycatcher	*Empidonax minimus*			X	
Barn Swallow	*Hirundo rustica*	X			
Wood Thrush	*Hylocichla mustelina*	X		X	
Baltimore Oriole	*Icterus galbula*	X			
Dark-eyed Junco	*Junco hyemalis*			X	X
Ring-billed Gull	*Larus delawarensis*	X		X	
Wild Turkey	*Meleagris gallopavo*	X	X	X	X
Song Sparrow	*Melospiza melodia*	X	X	X	
Black-and-White Warbler	*Mniotilta varia*	X			
Brown-headed Cowbird	*Molothrus ater*	X	X		
House Sparrow	*Passer domesticus*	X	X		
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	X			
Downy Woodpecker	*Picoides pubescens*	X		X	X
Black-capped Chickadee	*Poecile atricapillus*	X	X	X	X
Common Grackle	*Quiscalus quiscula*		X		
Golden-crowned Kinglet	*Regulus satrapa*			X	
Bank Swallow	*Riparia riparia*	X			
Eastern Phoebe	*Sayornis phoebe*	X	X	X	
Ovenbird	*Seiurus aurocapillus*	X			
American Redstart	*Setophaga ruticilla*	X	X	X	
White-breasted Nuthatch	*Sitta carolinensis*				X
American Tree Sparrow	*Spizella arborea*				X
Clay-colored sparrow	*Spizella pallida*	X	X		
Chipping Sparrow	*Spizella passerina*	X	X		
European Starling	*Sturnus Vulgaris*		X		
Tree Swallow	*Tachycineta bicolor*	X	X		
Carolina Wren	*Thryothorus ludovicianus*		X		
House Wren	*Troglodytes aedon*	X	X		
American Robin	*Turdus migratorius*	X	X	X	
Eastern Kingbird	*Tyrannus tyrannus*		X		
Philadelphia Vireo	*Vireo philadelphicus*		X		
Mourning Dove	*Zenaida macroura*	X	X	X	
White-throated Sparrow	*Zonotrichia albicollis*	X		X	

3.2 AREA 2: FIELDS BORDERED BY ROUTE 42, LAKEVIEW DRIVE, LAKE MICHIGAN, AND UNNAMED INTERMITTENT STREAM NORTH OF PLANT SITE

This portion of the site is primarily open field, in relatively early stages of succession. None of the fields in this area are currently under cultivation. Much of it is covered with various grasses, although vegetation characteristics vary from field to field. The northern portion of this area—approximately 15 acres[11]—is of the earliest succession stage, with small shrubs—mostly red osier dogwood—scattered around the field. Other vegetation includes milkweed (*Asclepias syriaca*), Canada thistle (*Cirsium arvense*), harebell (*Campanula rotundifolia*) and goldenrod. In the fall, this area also contained calico and New England aster.

Moving south from the open field, there is a small grove of green ash trees, which is bordered to the south by a line of aspens and balsam poplar (*Populus balsamifera*). Along the aspens, there is an old barbed wire fence, indicating this may have been an old farm border. This line of trees borders what appears to be a substantial (approximately 2-3 acre) wetland to the south. During the spring and the June portion of the summer survey, this wetland contained a substantial amount of water. In July and in the fall, the wetland was dry, but maintained other characteristics of a wetland. In the Winter, a very small (less than 100 square feet) area contained water. This wetland attracts a large number and diversity of birds (except in Winter), and deer tracks are plentiful. Although this wetland appears to be ideal amphibian habitat, none were seen or heard, and no egg masses were observed. Ground cover around the wetland includes ostrich fern (*Matteuccia struthiopteris*), marsh marigold (*Caltha palustris*), wild leek, cow parsnip, Virginia waterleaf, wild geranium (*Geranium maculatum*), Canada anemone (*Anemone canadensis*), Turk's cap lily (*Lilium superbum*) and horsetail. In the fall, the only flowering ground cover were goldenrod and asters.

The wetland continues south and eventually—at least during wet season—drains into the lake. This wetland—both the main portion and the part that flows south—is lined primarily with black willow, eastern cottonwood and quaking aspen. The main wetland is bordered on the southeast by a hill containing willows, aspen, sugar maple, basswood, sweet birch, eastern white pine (*Pinus strobus*), and spruce (*Picea sp.*).

The fields on either side of the wetland that runs to the south are of a slightly more advanced stage of succession, with heavy thickets of primarily red osier dogwood, along with green ash, small willows, tamarack (*Larix laricina*) and aspens. Other areas in these fields consist primarily of various grasses, along with large stands of white (*Melilotus alba*) and yellow sweet-clover (*Melilotus officinalis*), both considered to be significant invasive species. Other vegetation includes Queen Anne's lace, red clover, common fleabane, goldenrod and calico and New England aster. The field to the west also contains three more small wetlands: one ringed with cattails, and the others ringed primarily with small willows. During the spring and June surveys, all three contained water. In July and in the fall, only the southernmost contained water. This wetland also contained what appeared to be green frog tadpoles. In the winter, all three of these wetlands were filled with water.

In several areas of this field, there are groves of spruce, white pine and balsam fir trees, planted in a uniform manner. These trees were planted by volunteer employees several years ago.

The southern border of Area 2 is a small unnamed intermittent stream that empties into Lake Michigan just north of the plant. This stream drains a little less than one quarter of the site, and was flowing continuously during the Spring survey and, at a significantly reduced flow, during the Summer and Fall surveys. In the Winter, the stream was flowing at approximately the same rate as in the Spring. As is the case with the wetland to the north, this stream is lined with black willow and quaking aspen. A substantial buffer around this stream is heavily vegetated with shrubs, primarily red osier dogwood, but also some Russian olive. The area is teeming with deer trails, and deer were readily observed in the area.

The area contains habitat suitable for numerous species of mammals. Many deer were observed. Several active burrows were seen, but species could not be determined. Large predatory scat—likely that of a coyote—was observed. During the summer and fall surveys, several chipmunks were observed in the area of the large wetland. Several frogs were seen hopping into the stream, both in the spring and summer, but observation was too short for identification. In the fall, American toads could be heard throughout this area.

Butterflies observed here in the spring included cabbage white and monarch. In the summer, this list expanded to include common wood nymphs (*Cercyonis pegala*), great spangled fritillary (*Speyeria cybele*), black swallowtail (*Papilio polyxenes*), and clouded sulfur (*Colias philodice*). In the fall, monarchs, clouded sulfur, orange sulfur (*Colias eurytheme*), mourning cloak (*Nymphalis antiopa)* and cabbage whites were observed.

Birds observed are listed in Table 2.

Table 2: Birds Identified in Area 2, North Fields

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Red-winged Blackbird	*Agelaius phoeniceus*	X	X		
Mallard	*Anas platyrhynchos*	X	X	X	
Ruby-throated Hummingbird	*Archilochus colubris*		X		
Great Blue Heron	*Ardea herodias*	X	X		
Cedar Waxwing	*Bombycilla cedorum*		X	X	
Canada Goose	*Branta canadensis*			X	X
Great Horned Owl	*Bubo virginianus*			X	
Red-tailed Hawk	*Buteo jamaicensis*		X		
Green Heron	*Butorides virescens*	X			
Northern Cardinal	*Cardinalis cardinalis*		X		
American Goldfinch	*Carduelis tristus*	X	X	X	X
Veery	*Catharus fuscescens*	X			
Hermit Thrush	*Catharus guttatus*			X	
Brown Creeper	*Certhia americana*			X	
Northern Harrier	*Circus cyaneus*	X		X	
Northern Flicker	*Colaptes auratus*			X	
Northern Flicker	*Colaptes auratus*			X	
Eastern Wood-Pewee	*Contopus virens*		X		
American Crow	*Corvus brachyrhynchos*	X	X		X
Blue Jay	*Cyanocitta cristata*		X	X	
Yellow-rumped Warbler	*Dendroica coronata*	X		X	
Yellow Warbler	*Dendroica petechia*	X	X		
Bobolink	*Dolichonyx oryzivorus*	X	X		
Gray Catbird	*Dumetella carolinensis*	X	X	X	
Peregrine Falcon	*Falco peregrinus*		X	X	
Common Yellowthroat	*Geothlypis trichas*	X	X		
Sandhill Crane	*Grus Canadensis*	X			
Barn Swallow	*Hirundo rustica*	X	X		
Wood Thrush	*Hylocichla mustelina*			X	
Dark-eyed Junco	*Junco hyemalis*			X	
Ring-billed Gull	*Larus delawarensis*	X			
Wild Turkey	*Meleagris gallopavo*	X			
Song Sparrow	*Melospiza melodia*	X	X		
Black-and-White Warbler	*Mniotilta varia*			X	
Brown-headed Cowbird	*Molothrus ater*	X	X		
Connecticut Warbler	*Oporornis agilis*		X		

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Mourning Warbler	*Oporornis philadelphia*			X	
Eastern Screech-Owl	*Otus asio*			X	
Rose-breasted Grosbeak	*Pheucticus ludovicianus*			X	
Downy Woodpecker	*Picoides pubescens*	X	X		
Three-toed Woodpecker	*Picoides tridactylus*		X	X	
Black-capped Chickadee	*Poecile atricapillus*		X	X	X
Blue-gray Gnatcatcher	*Polioptila caerulea*		X		
Common Grackle	*Quiscalus quiscula*	X	X		
Golden-crowned Kinglet	*Regulus satrapa*			X	
Bank Swallow	*Riparia riparia*	X			
Eastern Phoebe	*Sayornis phoebe*			X	
American Woodcock	*Scolopax minor*	X	X		
American Redstart	*Setophaga ruticilla*		X		
White-breasted Nuthatch	*Sitta carolinensis*		X	X	
Yellow-bellied Sapsucker	*Sphyrapicus varius*			X	
American Tree Sparrow	*Spizella arborea*				X
Clay-colored sparrow	*Spizella pallida*	X	X		
Field Sparrow	*Spizella pusilla*			X	
Meadowlark	*Sturnella sp.*	X	X		
European Starling	*Sturnus vulgaris*		X	X	
Tree Swallow	*Tachycineta bicolor*	X	X		
Carolina Wren	*Thryothorus ludovicianus*		X		
House Wren	*Troglodytes aedon*	X	X		
Winter Wren	*Troglodytes troglodytes*		X		
American Robin	*Turdus migratorius*	X	X	X	
Eastern Kingbird	*Tyrannus Tyrannus*		X		
Blue-headed Vireo	*Vireo solitarius*		X	X	
Mourning Dove	*Zenaida macroura*	X	X		
White-throated Sparrow	*Zonotrichia albicollis*	X		X	

3.3 AREA 3: PLANT SITE AND IMMEDIATE VICINITY

Area 3 is bounded to the north by the unnamed intermittent stream; to the east by the beach on Lake Michigan; to the west by State Route 42, and to the south by a large rock barrier. The area includes the plant site and associated equipment, including the switchyard, parking lots, site access road, the sewage treatment plant, and the meteorological towers. It also includes an unnamed intermittent stream to the south of the plant, into which the sewage treatment plant effluent flows.

North of Plant

The northern boundary of this area is the southern bank of the intermittent stream discussed above in Area 2. This side of the stream is very similar to that described above, with stands of red osier dogwood, some Russian olive, quaking aspen, black willows, and ash trees by streamside. Immediately south of the stream is an area of open field typical of recent disturbance. It consists primarily of grasses, but also contains white sweet-clover, yellow sweet-clover, red clover, bull thistle (*Cirsium vulgare*), dock (*Rumex sp.*), dandelion, horsetail, ox-eye daisy, common mullein (*Verbascum thapsis*), Canada thistle, winter cress (*Barbarea vulgaris*), common burdock (*Arctium minus*), common blue violet, goldenrod (*Solidago sp.*), starry false Solomon's seal (*Maianthemum stellatum*), calico and New England aster and milkweed (*Asclepias syriaca*).

The eastern end of the intermittent stream culminates in a retention pond built during the original plant construction. Its outfall flows via a conduit pipe to a gully that empties into Lake Michigan. The pond is surrounded by many of the plants discussed above, as well as a stand of May apple (*Podophyllum peltatum*), and large numbers of Dame's rocket. As has been the case elsewhere on site, the retention pond appears to be viable amphibian habitat, and though none were seen or heard during the spring survey, numerous small tadpoles were observed in the summer. A green frog was also observed in the pond. During the fall survey, no amphibians were observed in the pond or stream; however, American toads were either heard or observed throughout this area.

South of the pond is a recreation area of approximately 7 acres[12] which includes a ballfield. The area includes large aspens, eastern cottonwood, Russian olive, black willow, a small grove of apple trees (*Malus pumila*), ash, and thickets of red osier dogwood. To the immediate south, just north of the north parking lot, is a stand of eastern white pine (*Pinus strobus*). A number of small ash trees comprise the understory of this pine grove. A wetland of approximately 0.37 acre was identified in this area as part of the ISFSI project.

A ramp that descends from the parking lot to the shore is lined with various grasses, as well as white campion, crown vetch (*Coronilla varia*), and hairy vetch (*Vicia villosa*). During the July survey, this area was heavily dominated by crown vetch and Canada thistle. In the fall, crown vetch continued to be dominant, but goldenrod and asters were also observed.

Another grove of evergreens—primarily white pine—is located immediately west of the ballfield. The area also contains ash, black cherry (*Prunus serotina*), and red osier dogwood.

Immediately north of the switchyard is an area of approximately 2 acres, which is in a state of early to intermediate succession. The predominant vegetation is red osier dogwood, but the area also includes sandbar willow (*Salix interior*), black cherry, and small quaking aspen. Other vegetation includes white sweet-clover, red clover, crown vetch and Queen Anne's lace.

The diversity of vegetation in this entire area attracts birds and mammals. Numerous eastern cottontails (*Sylvilagus floridanus*) were seen, and deer sign was plentiful. Birds found in the area are included in Table 3 below.

South of Plant

The area immediately south of the plant contains an unnamed intermittent stream that drains much of the central and southern portion of the site. This stream also flowed during the spring survey. The sewage treatment plant effluent also drains into this stream. In July and in the fall, the stream above the road leading up to the sewage plant was not flowing at all, and only occasional shallow stagnant pools were seen in this area.

Upstream of the road to the sewage facility, the vegetation that is not mowed is relatively narrow and close to the stream. It consists primarily of small black willow trees, red osier dogwood, and small green ash trees. Approaching the western edge of this area, the vegetation is dominated by larger willow, a few large quaking aspen, and more ash trees. A small tributary provides an avenue for drainage from some portions of the site. A wood frog (*Rana sylvatica*) was identified near this tributary in the spring. None were observed in the summer or fall. Ground cover in this area includes dandelions, common violet, horsetails, goldenrod and wild geranium (*Geranium maculatum*).

Downstream of the road to the sewage treatment facility, the immediate vicinity of the stream channel is heavily dominated by large green ash trees, which give way to large black willows halfway to the outlet to Lake Michigan. Immediately upstream of the creek mouth, green ash reestablishes dominance. Ground cover is predominantly common violet, common burdock, and winter cress. On the south side of this stream, the terrain rises up a hill of approximately 20 feet. The hill is inhabited by a combination of large quaking aspens, paper birch, and ash trees. Deer tracks, as is the case on most of the property, were evident.

South of the stream, Area 3 is dominated by low-lying vegetation that is periodically cut. The area is dominated by grasses, but also includes a substantial amount of white and yellow sweet-clover, spotted knapweed (*Centaurea biebersteinii*), crown vetch, dandelion, silverweed (*Argentina anserina*), horsetails, Queen Anne's lace, bull thistle, bird's-foot trefoil, common burdock, common mullein, goldenrod, calico and New England aster, and winter cress.

Immediately south of the sewage facility is a small area that was wet in the spring and dry in the summer and fall. The area is surrounded by red osier dogwood. Common cattail (*Typha latifolia*) are predominant in the wet area. Spring peepers (*Pseudacris crucifer*) were evident during the spring survey. This area may have evolved wetland-like characteristics because of its history as an area of sludge spreading. A green frog (*Rana clamitans*) was observed in a settlement lagoon associated with the sewage treatment facility. In the fall, toads were the only amphibians heard or observed.

This area also contains an approximately 4-acre tract[13] in early succession, dominated by red osier dogwood, small ash trees, various grasses, white and yellow sweet-clover, and crown vetch. The area provides diverse habitat for numerous bird species, whitetail deer, raccoon and eastern cottontail.

Mammals observed directly in Area 3 included deer, eastern cottontail, chipmunk, and thirteen-lined ground squirrel (*Spermophilus tridecemlineatus*). Additionally, a striped skunk (*Mephitis mephitis*) was reported in the protected area.

Amphibians observed directly included green frog, wood frog, and American toad. As was the case throughout the site, no reptiles were observed.

Butterflies seen in this area in the spring included the clouded sulfur (*colias philodice*) and monarch *(Danaus plexippus)*. In the summer, this list expanded to include pearl crescent (*Phyciodes tharos*), mourning cloak (*Nymphalis antiopa),* black swallowtail (*Papilio polyxenes*), red admiral (*Vanessa atalanta*), common wood nymph (*Cercyonis pegala*), and cabbage white *(Pieris rapae).* In the fall, clouded sulfur were observed.

Birds observed in Area 3 are listed in Table 3 below.

Table 3: Birds Identified in Area 3, Vicinity of Plant

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Red-winged Blackbird	*Agelaius phoeniceus*	X	X		
Mallard	*Anas platyrhynchos*	X	X		
Great Blue Heron	*Ardea herodias*			X	
Cedar Waxwing	*Bombycilla cedrorum*		X		
Canada Goose	*Branta canadensis*			X	X
Northern Cardinal	*Cardinalis cardinalis*	X	X		
American Goldfinch	*Carduelis tristus*	X	X	X	X

Common Name	Scientific Name	Spring	Summer	Fall	Winter
House Finch	*Carpodacus mexicanus*	X			
Purple Finch	*Carpodacus purpureus*	X	X		
Chimney Swift	*Chaetura pelagica*		X		
Killdeer	*Charadrius vociferus*	X	X	X	
Northern Flicker	*Colaptes auratus*			X	
Rock Dove (Pigeon)	*Columbia livia*	X	X	X	X
American Crow	*Corvus brachyrhynchos*	X		X	X
Blue Jay	*Cyanocitta cristata*	X		X	
Yellow-rumped Warbler	*Dendroica coronata*	X		X	
Magnolia Warbler	*Dendroica magnolia*	X			
Palm Warbler	*Dendroica palmarum*	X			
Yellow Warbler	*Dendroica petechia*	X	X		
Gray Catbird	*Dumetella carolinensis*	X	X	X	
Peregrine Falcon	*Falco peregrinus*	X	X	X	X
Common Yellowthroat	*Geothlypis trichas*	X		X	
Barn Swallow	*Hirundo rustica*	X	X		
Wood Thrush	*Hylocichla mustelina*			X	
Dark-eyed Junco	*Junco hyemalis*				X
Ring-billed Gull	*Larus delawarensis*	X			
Wild Turkey	*Meleagris gallopavo*	X			
Song Sparrow	*Melospiza melodia*	X	X	X	
Black-and-White Warbler	*Mniotilta varia*	X			
Brown-headed Cowbird	*Molothrus ater*	X			
House Sparrow	*Passer domesticus*	X	X		
Indigo Bunting	*Passerina cyanea*		X		
Downy Woodpecker	*Picoides pubescens*				X
Snow Bunting	*Plectrophenax nivalis*				X
Black-capped Chickadee	*Poecile atricapillus*		X	X	X
Common Grackle	*Quiscalus quiscula*	X			
Golden-crowned Kinglet	*Regulus satrapa*			X	
Eastern Phoebe	*Sayornis phoebe*	X	X		
American Woodcock	*Scolopax minor*			X	
Eastern Bluebird	*Sialia sialis*	X			
Red-breasted Nuthatch	*Sitta canadensis*	X			X
Yellow-bellied Sapsucker	*Sphyrapicus varius*			X	
American Tree Sparrow	*Spizella arborea*				X
Clay-colored sparrow	*Spizella pallida*	X	X		

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Field Sparrow	*Spizella pusilla*			X	
European Starling	*Sturnus Vulgaris*	X	X	X	
Tree Swallow	*Tachycineta bicolor*	X	X		
Carolina Wren	*Thryothorus ludovicianus*		X		
House Wren	*Troglodytes aedon*	X	X		
American Robin	*Turdus migratorius*	X	X	X	
Eastern Kingbird	*Tyrannus tyrannus*	X	X		
Nashville Warbler	*Vermivora ruficapilla*	X			
Mourning Dove	*Zenaida macroura*	X	X		
White-throated Sparrow	*Zonotrichia albicollis*			X	
White-crowned Sparrow	*Zonotrichia leucophrys*	X			

3.4 AREA 4: SCHOOL FOREST AND SURROUNDINGS

Area 4 is bounded on the north by the large rock barrier; to the east by the Lake Michigan shore; to the west by State Route 42; and to the south by the property line. It consists of a variety of habitats, including the Joe Krofta Memorial Forest ("School Forest"), large areas of open fields in various stages of succession, a small pond and surrounding wetland, the upstream portion of the unnamed intermittent stream south of the plant, and one field under lease to a local farmer.

The pond/wetland complex is immediately to the northeast of the School Forest parking lot. It is surrounded by a large field in early succession, with grasses being the dominant vegetation, but with large groves of red osier dogwood and small green ash, along with large quantities of white sweet-clover. Common burdock, Canada thistle, common fleabane, ox-eye daisy, dandelion, Virginia waterleaf, yarrow (*Achillea millefolium*), goldenrod, calico and New England aster, and Queen Anne's lace are also found in this area. A number of small white cedars are present, which are heavily browsed by deer.

During the spring survey, the pond was used by waterfowl, including Canada geese (*Branta canadensis*), mallard (*Anas platyrhynchos*) and blue-winged teal (*Anas discors*). While no amphibians or turtles were observed in the spring, green frogs, wood frogs and chorus frogs (*Pseudacris triseriata*) were very evident in the summer survey. A number of small willow and cottonwood line a small outflow from the pond into the forest. In the fall, the pond was being used by mallards.

As discussed in the introduction, the forest itself was planted and cared for by Joe Krofta, a previous owner of the land. As a result, the forest contains a variety of species, some of which are not normally found in the area, and none of which stand out as the predominant species. The forest does provide a diversity of habitat for area fauna, including cover provided by stands of evergreen trees, and food provided by the diversity of vegetation. The forest also includes several expanses of wetland, containing typical wetland vegetation.

Trees present in the forest include: black cherry, white birch, white pine, spruce, yellow birch, sugar maple, aspen, hemlock, balsam, scotch pine, American beech, red maple (*Acer rubrum*), green ash, black oak (*Quercus velutina*), and hawthorn. Ground cover includes crown vetch, common burdock, common violet, downy yellow forest violet, wild leek, extensive areas of May apple, horsetail, large fields of marsh marigold, ostrich fern, goldenrod, asters, Virginia waterleaf, starry false Solomon's seal, orange hawkweed, cow parsnip, jewelweed, raspberry, wild geranium, and nodding trillium (*Trillium cernum*).

The northern edge of the forest opens into an extensive (4-5 acre) area of trees planted by employees and the previous owner a number of years ago. They consist largely of spruce and balsam trees. The area has an abundance of birds and whitetail deer. In July, much of the area was covered with crown vetch.

To the west of this tree grove is a field in intermediate succession, with thick groves of red osier dogwood, taller aspen, black willow, green ash and sandbar willow. Just to the west of the intermittent stream is a wooded area in two stages of succession: nearest to Route 42 is a wooded area with trees less than 6 inches in diameter, which is bordered to the east by trees ranging from 4 to 18 inches in diameter.

To the south of the School forest is another field in early to intermediate succession, with red osier dogwood, sandbar willow, ash, and basswood. It also contains planted evergreen trees bordered to the west by a field currently under cultivation. During the July survey, the groundcover in this area was heavily dominated by crown vetch. In the fall, goldenrod and asters joined the crown vetch as dominant species.

Finally, south of the cultivated field, the southernmost end of the site is drained to the lake via a concrete culvert under State Route 42, which empties into an intermittent drainage channel. This channel is lined primarily with boxelder (*Acer negundo*), along with some areas of red osier dogwood. A small number of ash trees become prevalent as the channel approaches the lake.

Mammals found in Area 4—either observed directly or via spoor—included deer, opossum (*Didelphus marsupialis*), raccoon (*Procyon lotor*), eastern cottontail, fox squirrel (*Sciurus niger*), chipmunk and coyote (*Canis latrans*).

Amphibians included wood frog, green frog, American toad, and chorus frog. Monarch butterflies were observed in the spring. In the summer, this list expanded to include silvery checkerspot (*Chlosyne nycteis*) and common wood nymphs (*Cercyonis pegala*). In the fall, clouded sulfur and monarchs were observed.

Birds observed in Area 4 are listed in Table 4 below.

Table 4: Birds Identified in Area 4, School Forest and Surroundings

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Red-winged Blackbird	*Agelaius phoeniceus*	X	X	X	
Blue-winged Teal	*Anas discors*	X			
Mallard	*Anas platyrhynchos*	X	X	X	
Ruby-throated Hummingbird	*Archilochus colubris*		X		
Great Blue Heron	*Ardea herodias*			X	
Short-eared Owl	*Asio flammeus*				X
Cedar Waxwing	*Bombycilla cedrorum*		X		
Canada Goose	*Branta canadensis*	X		X	X
Great Horned Owl	*Bubo virginianus*	X	X		
Red-Tailed Hawk	*Buteo jamaicensis*		X	X	X
Northern Cardinal	*Cardinalis cardinalis*	X	X	X	
American Goldfinch	*Carduelis tristus*	X	X	X	X
Purple Finch	*Carpodacus purpureus*		X		
Turkey Vulture	*Cathartes aura*			X	
Brown Creeper	*Certhia americana*			X	
Killdeer	*Charadrius vociferus*	X			
Northern Flicker	*Colaptes auratus*	X	X	X	
Eastern Wood-Pewee	*Contopus virens*		X	X	
American Crow	*Corvus brachyrhynchos*	X	X	X	X
Blue Jay	*Cyanocitta cristata*	X	X	X	
Yellow-rumped Warbler	*Dendroica coronata*	X		X	
Magnolia Warbler	*Dendroica magnolia*	X			
Palm Warbler	*Dendroica palmarum*	X		X	
Yellow Warbler	*Dendroica petechia*	X	X		
Gray Catbird	*Dumetella carolinensis*	X	X	X	
Peregrine Falcon	*Falco peregrinus*			X	X
Common Yellowthroat	*Geothlypis trichas*		X		
Wood Thrush	*Hylocichla mustelina*		X	X	

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Dark-eyed Junco	*Junco hyemalis*			X	
Wild Turkey	*Meleagris gallopavo*	X	X		
Swamp Sparrow	*Melospiza georgiana*		X		
Song Sparrow	*Melospiza melodia*	X	X	X	
Brown-headed Cowbird	*Molothrus ater*		X		
Osprey	*Pandion haliaetus*	X			
Indigo Bunting	*Passerina cyanea*		X		
Double-crested Cormorant	*Phalacrocorax auritus*	X			
Rose-breasted Grosbeak	*Pheucticus ludovicianus*		X		
Downy Woodpecker	*Picoides pubescens*	X	X	X	
Hairy Woodpecker	*Picoides villosus*			X	
Black-capped Chickadee	*Poecile atricapillus*		X	X	
Blue-gray Gnatcatcher	*Polioptila caerulea*	X		X	
Purple Martin	*Progne subis*		X		
Golden-crowned Kinglet	*Regulus satrapa*			X	
Bank Swallow	*Riparia riparia*		X		
Eastern Phoebe	*Sayornis phoebe*		X	X	
American Woodcock	*Scolopax minor*		X	X	
Ovenbird	*Seiurus aurocapillus*	X			
American Redstart	*Setophaga ruticilla*		X		
Eastern Bluebird	*Sialia sialis*		X		
White-breasted Nuthatch	*Sitta carolinensis*		X	X	X
Yellow-bellied Sapsucker	*Sphyrapicus varius*			X	
American Tree Sparrow	*Spizella arborea*				X
Clay-colored sparrow	*Spizella pallida*	X	X	X	
Chipping Sparrow	*Spizella passerina*		X		
Field Sparrow	*Spizella pusilla*			X	
European Sparling	*Sturnus vulgaris*		X		
Tree Swallow	*Tachycineta bicolor*	X	X		
Carolina Wren	*Thryothorus ludovicianus*		X		
House Wren	*Troglodytes aedon*	X	X		
Winter Wren	*Troglodytes troglodytes*		X		
American Robin	*Turdus migratorius*	X	X	X	
Eastern Kingbird	*Tyrannus tyrannus*		X		
Nashville Warbler	*Vermivora ruficapilla*	X			
Canada Warbler	*Wilsonia canadensis*			X	
Mourning Dove	*Zenaida macroura*		X	X	X

Common Name	Scientific Name	Spring	Summer	Fall	Winter
White-throated Sparrow	*Zonotrichia albicollis*	X		X	
White-crowned Sparrow	*Zonotrichia leucophrys*			X	

3.5 AREA 5: LAKE MICHIGAN SHORE AND ADJACENT WATERS

The KPS site includes nearly two miles of Lake Michigan shoreline. As discussed in the Introduction, the nature of shoreline habitat is strongly influenced by the water level in the lake. At present, lake levels are relatively low compared to the past 90 years, creating a beach habitat that is somewhat wider than average. The entire extent of the KPS shoreline was surveyed, to characterize habitat, and to examine species present during the survey.

Because the Great Lakes population of the piping plover (*Charadrius melodus*) is highly endangered, this survey includes two focused efforts: first, determining if any piping plovers were present, either during migration or the nesting season; and second, absent any piping plovers, ascertaining whether nesting habitat could exist in the future, should the plover attempt to nest in this area. Further discussion of this facet of the survey is provided in the "Threatened and Endangered Species" section below.

North of Sandy Bay Creek

The beach on Dominion property north of the mouth of Sandy Bay Creek spans approximately 0.22 mile. North of the property, the beach continues, but becomes somewhat narrower.

The beach in this area abuts a steep cliff, which shows signs of past erosion. Small aspen, eastern cottonwood and sandbar willows line the base of the cliff. Small patches of silverweed (*Argentina anserina*), American beach grass (*Ammophila brevigulata*), white sweet-clover and horsetails provide low-lying vegetation in this area. The majority of the cliff face itself is covered with white sweet-clover. The sparsely vegetated portion of the beach—that between the water's edge and the line of trees—varies at present from approximately 60 feet wide down to 15 to 20 feet, with much of it greater than 30 feet. In the fall, the primary vegetation on the cliffside consisted of New England Aster, calico aster and goldenrod.

The area has an abundance of various swallows, including bank swallows, which have excavated the cliff banks for nesting. During the fall survey, it was noted that all of the swallows had left. While the beach appears to provide potential breeding habitat for shore birds, none were observed on this part of the beach. Great blue herons were observed regularly.

Bank swallow nesting area

Silverweed

Birds observed in this area are included in Table 5 below.

South of Sandy Bay Creek to Plant Discharge

The beach between Sandy Bay Creek and the discharge spans approximately 0.8 mile. The beach abuts a cliff for much of this span; however, the cliff height is reduced considerably two to three hundred yards north of the plant itself. As is the case to the north, the cliff continues to show signs of past erosion. Aspens, eastern cottonwood and sandbar willows of various sizes line the base of the cliff, along with scattered red osier dogwood and Russian olive.

In some areas of the beach here, short (12 feet or less) aspens and willows occupy the middle of the beach. American beach grass, common evening primrose (*Oenothera biennis*), common milkweed (*Asclepias syriaca*), goldenrod, Canada thistle, black-eyed Susans, horsetails, silverweed, New England and calico aster, and white sweet-clover provide shorter vegetation, as well as a small amount of wild rose (*Rosa blanda*). Directly adjacent to the plant, the beach is strongly dominated by white sweet-clover. For most of the property north of the plant, white sweet-clover dominates the cliff vegetation.

The sparsely vegetated portion of the beach here varies considerably, from approximately 80 feet nearby the plant, to less than 15 feet farther north, back up to 60 feet closer to Sandy Bay Creek; overall, however, much of this beach is at least 30 feet wide at present lake level.

Deer tracks and occasional raccoon tracks were in evidence on this stretch of beach, during all four seasons. In the fall and winter, coyote tracks were noted, and on September 26, coyote howls were heard from nearby. A variety of birds were observed, mostly gulls, terns and various ducks. Only one species of shore bird—the spotted sandpiper (*Actitis macularia*)—was observed. It was observed during the spring, summer and fall surveys.

During a two-day period, on May 11-12, a migration of thousands of Bonaparte's gulls (*Larus philadelphia*) flew northward past this area. By the summer survey, the migration had ended and only eight Bonaparte's gulls were observed. None were observed in the fall or winter.

Caspian terns (*Sterna caspia*), listed by Wisconsin as a state threatened species, were observed on site throughout the spring survey period, and in the June portion of the summer survey. In July, only one Caspian tern was observed, and in the fall and winter, none were seen. Other birds observed in this area are listed in Table 5 below.

South of Plant Discharge

The shore from the discharge south spans approximately 0.75 mile. The characteristics of the shore in this area are considerably different from those to the north. With the exception of a small stretch of beach between the discharge and the intermittent stream south of the plant—where the beach varies from approximately 30 feet down to no beach at all—the beach south of the plant is very narrow. At one point south of the stream, a 100-yard stretch of beach, approximately 15 feet wide, is interrupted by a wide path of eastern cottonwood, aspen and sandbar willow thicket, which is abutted inland by 5 to 10 more feet of beach. Large areas of sweet-clover are also found here. Other vegetation includes dame's rocket, silverweed, common mullein, ox-eye daisy, fistulous goat's beard (*Tragopogon dubius*), and hound's tongue (*Cynoglossum officinale*). In the fall, goldenrod and calico aster were predominant.

Further south of this area, the beach is less than 15 feet wide and, for most of the distance, essentially non-existent. Much of the area was lined with rip-rap in the late 1980s to combat severe cliff erosion that was taking place at that time, and even at present, the water is at the base of much of the rip-rap. Adjacent to the School Forest area, paper birch, eastern cottonwood, aspens, willow, red pine and balsam trees are found directly inland of the rip-rap.

Deer and raccoon tracks were evident here, as well as what appeared to be fox tracks. In June, a raccoon was observed foraging on the beach. The spotted sandpiper was the only shorebird observed on the shore; however, killdeer (*Charadrius vociferus*) were observed flying overhead. Other birds observed in this area are listed in Table 5 below.

Overall in Area 5, the only butterfly observed on the shore in the spring was the monarch. In the summer survey, in addition to monarchs, other butterflies observed included cabbage white and red admiral (*Vanessa atalanta*). In the fall, monarch and cabbage white were seen.

Table 5: Birds Identified in Area 5, Shoreline and Adjacent Waters

Common Name	**Scientific Name**	**Spring**	Summer	**Fall**	Winter
Spotted Sandpiper	*Actitis macularia*	X	X	X	
Red-winged Blackbird	*Agelaius phoeniceus*		X		
American Wigeon	*Anas americana*				X
Mallard	*Anas platyrhynchos*	X	X	X	X
Black Duck	*Anas rubripes*				X
Gadwall	*Anas strepera*	X	X		
Greater White-fronted Goose	*Anser albifrons*				X
Ruby-throated Hummingbird	*Archilochus colubris*		X		
Great Blue Heron	*Ardea herodias*	X	X	X	
Redhead	*Aythya americana*			X	X
Canada Goose	*Branta canadensis*	X	X	X	X
Bufflehead	*Bucephala albeola*	X			X
Common Goldeneye	*Bucephala clangula*		X		X
American Goldfinch	*Carduelis tristis*		X		
Purple Finch	*Carpodacus purpureus*	X	X		
Belted Kingfisher	*Ceryle alcyon*		X		
Killdeer	*Charadrius vociferus*	X			
Northern Flicker	*Colaptes auratus*			X	
American Crow	*Corvus brachyrhynchos*		X		X
Blue Jay	*Cyanocitta cristata*			X	
Yellow-rumped Warbler	*Dendroica coronata*			X	
Peregrine Falcon	*Falco peregrinus*		X		
American Coot	*Fulica americana*				X
Common Loon	*Gavia immer*	X			
Barn Swallow	*Hirundo rustica*	X	X		
Herring Gull	*Larus argentatus*	X	X	X	X
Ring-billed Gull	*Larus delawarensis*	X	X	X	X
Great Black-backed Gull	*Larus marinus*			X	X
Bonaparte's Gull	*Larus philadelphia*	X	X		
Song Sparrow	*Melospiza melodia*	X	X		
Red-breasted Merganser	*Mergus serrator*	X			X
Cliff Swallow	*Petrochelidon pyrrhonota*	X			
Double-crested Cormorant	*Phalacrocorax auritus*	X			X
Common Grackle	*Quiscalus quiscula*		X		
Golden-crowned Kinglet	*Regulus satrapa*			X	

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Bank Swallow	*Riparia riparia*	X	X		
Eastern Phoebe	*Sayornis phoebe*	X		X	
American Tree Sparrow	*Spizella arborea*				X
Field Sparrow	*Spizella pusilla*			X	
Caspian Tern	*Sterna caspia*	X	X		
Tree Swallow	*Tachycineta bicolor*		X		
House Wren	*Troglodytes aedon*	X			
American Robin	*Turdus migratorius*	X	X	X	

3.6 AREA 6: NORTHERN LEASED FARMLAND AND INTERMITTENT STREAM NORTH OF SANDY BAY CEMETERY

Area 6 is bounded on the north and west by the property line; on the east by State Route 42; and on the south by the southern extent of land leased by Mr. Steven Schleis. The overwhelming majority of this land, as well as that for Areas 7 and 8, is leased for farming, and most of it was viewed only from a distance, due to either recent tilling or standing crops. Most of the tilled land during the spring survey was barren of fauna, with the exception of animal tracks, and occasional birds seeking upturned worms. In the summer, fall and winter, some additional wildlife was observed within the cropland. Most of the description below pertains to that area north of Sandy Bay Cemetery that is not farmed.

West of State Route 42, the stream that divides Areas 2 and 3 flows from the west end of the property just north of the cemetery. The unleased portion of this area comprises approximately 26 acres of woodland/riverine habitat. There is a wide diversity of vegetation in this area, creating habitat for a multitude of mammal and bird species. The stream was flowing during the spring and winter surveys. In the summer and fall, the stream was not flowing in this area, with the exception of the channel within approximately 250 yards of Route 42, which was at a significantly reduced flow. The intermittent nature of this stream was indicated by the apparent lack of any fish.

For most of this tract, this stream meanders across a wide flood plain, indicating that it may have flowed more regularly in the past than it does now. The floodplain is surrounded on both sides by a diversity of large trees, including spruce, balsam, apple, green ash, aspen, willows, paper birch, white cedar, basswood, red oak, boxelder, sweet crabapple (*Malus coronaria*), American elm (*Ulmus americana*), sweet birch and hawthorn. Hawthorn is far more dominant in this habitat than elsewhere on site. The floodplain itself consists primarily of grasses, but also includes common burdock, horsetails, jewelweed, Canada thistle, yellow sweet-clover, goldenrod, calico aster, and winter cress. The floodplain also contains extensive thickets of small sandbar willow and red osier dogwood, and a few areas with Russian olive.

The area next to Route 42 and the edge of the tilled fields contain various grasses, several small boxelders, burdock, wild rose (*Rosa blanda*), fistulous goat's beard (*Tragopogon dubius*), white campion, goldenrod, aster and Russian olive.

The western end of this tract opens up into a large open field that contains three small channels that drain into the main stream. The area, including the tilled farmland, contains abundant mammal sign, including deer, coyote, eastern cottontail, fox and raccoon. An oppossum was observed on the edge of one of the tilled fields during a night walk. A coyote pup, shown below, was discovered in the area. In the fall, a short-tailed shrew (*Blarina brevicada*) was observed. Wood frogs, also shown below, also inhabit the area. American toads were seen and heard during the fall. In the winter, several deer and a coyote were observed.

Coyote Pup

Wood Frog

Butterflies seen in this area in the spring included the clouded sulfur (*colias philodice*) and monarch *(Danaus plexippus).* In the summer, this list expanded to include black swallowtail (*Papilio polyxenes*) and common wood nymph (*Cercyonis pegala*). Only monarchs were observed here in the fall.

Birds observed in this area are listed in Table 6 below.

Table 6: Birds Identified in Area 6, Upstream of North Intermittent Stream

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Red-winged Blackbird	*Agelaius phoeniceus*	X	X	X	
Cedar Waxwing	*Bombycilla cedrorum*		X	X	X
Canada Goose	*Branta canadensis*				X
Northern Cardinal	*Cardinalis cardinalis*	X	X		X
American Goldfinch	*Carduelis tristus*	X	X	X	X
House Finch	*Carpodacus mexicanus*		X		X
Purple Finch	*Carpodacus purpureus*		X		
Killdeer	*Charadrius vociferus*		X		
Northern Flicker	*Colaptes auratus*			X	
American Crow	*Corvus brachyrhynchos*	X	X		X
Blue Jay	*Cyanocitta cristata*			X	
Yellow-rumped Warbler	*Dendroica coronata*	X		X	
Yellow Warbler	*Dendroica petechia*	X			
Bobolink	*Dolichonyx oryzivorus*		X		
Gray Catbird	*Dumetella carolinensis*	X	X	X	
Horned Lark	*Eremophila alpestris*	X			
Common Yellowthroat	*Geothlypis trichas*	X			
Barn Swallow	*Hirundo rustica*	X	X		
Dark-eyed Junco	*Junco hyemalis*			X	X
Herring Gull	*Larus argentatus*	X			
Ring-billed Gull	*Larus delawarensis*	X			
Wild Turkey	*Meleagris gallopavo*			X	X
Song Sparrow	*Melospiza melodia*	X	X	X	
Brown-headed Cowbird	*Molothrus ater*	X	X		
Downy Woodpecker	*Picoides pubescens*			X	X
Black-capped chickadee	*Poecile atricapillus*		X	X	X
Common Grackle	*Quiscalus quiscula*		X		
Golden-crowned Kinglet	*Regulus satrapa*				X
Eastern Phoebe	*Sayornis phoebe*		X		
American Redstart	*Setophaga ruticilla*		X		
Red-breasted Nuthatch	*Sitta canadensis*				X
American Tree Sparrow	*Spizella arborea*				X
Clay-colored sparrow	*Spizella pallida*	X	X	X	
Chipping Sparrow	*Spizella passerina*		X		
Field Sparrow	*Spizella pusilla*			X	
Meadowlark	*Sturnella sp.*		X		

Common Name	Scientific Name	Spring	Summer	Fall	Winter
European Starling	*Sturnus Vulgaris*	X	X	X	
Northern Hawk Owl	*Surnia ulula*				X
Tree Swallow	*Tachycineta bicolor*	X	X		
Carolina Wren	*Thryothorus ludovicianus*		X		
Brown Thrasher	*Toxostoma rufum*				X
House Wren	*Troglodytes aedon*	X			
American Robin	*Turdus migratorius*	X	X	X	
Mourning Dove	*Zenaida macroura*		X		
White-throated Sparrow	*Zonotrichia albicollis*	X		X	
White-crowned Sparrow	*Zonotrichia leucophrys*	X			

3.7 AREA 7: LEASED LAND AND OPEN AREA ON EITHER SIDE OF NUCLEAR ROAD

Area 7 is bordered on the north by the Steven Schleis lease; on the west by the property line; on the east by State Route 42; and on the south by the Wotachek lease. With the exception of approximately 44 acres north of Nuclear Road, this entire area is leased farmland. The general character of the terrain in this area is gently rolling hills.

During the spring survey, the leased land, all of which had been recently tilled, was observed primarily from a distance. In the summer and fall surveys, the perifery of the leased land was walked using a field access road on the north and a field boundary line on the south. An area of the main channel of the south intermittent stream, where tilling is not performed, was also walked. A small (1-2 acre) woodlot just south of Nuclear Road and west of Route 42 was examined during the fall survey. This woodlot consists primarily of green ash, but also contains several sugar maples, two northern white cedar and two locust trees. The unleased land includes the Site Boundary Facility (SBF), a small building on Nuclear Road. It also includes several transmission towers for the lines exiting the plant.

To the immediate north and west of the SBF, a number of boxelder, large black willows and red osier dogwood line a small drainage channel, which ultimately empties into the southern unnamed intermittent stream. This channel flows to the northeast, and then to the east. As it flows to the east, it goes through two stands of small sandbar willow and red osier dogwood, which are inhabited by a number of birds. Other trees include a lone spruce and eastern hemlock (*Tsuga canadensis*).

The vast majority of this area is characterized as early succession, with primarily grasses, small red osier dogwood, some fields of white sweet-clover, and some Queen Anne's lace. The border between the unleased land and the leased field to the east is lined with small spruce trees, red osier dogwood, and highbush cranberry (*Viburnum opulus* subsp. *trilobum*). In the fall, as elsewhere on site, this area contained a significant amount of calico aster and goldenrod. Along Nuclear Road, a line of trees, primarily spruce and birches, provide perches for birds, most notably, red-winged blackbird. In the spring, the drainage channels present in the area were flowing, but the area had experienced substantial recent rains. During the summer and fall surveys, all of the channels in this area were completely dry. The main channel south of Nuclear Road was traversed, and found to contain stands of small sandbar willow, grasses, and red clover.

The access road on the northern edge of Area 7 is characterized primarily with grasses, but also includes red clover, red osier dogwood, Russian olive and small numbers of trees, including green ash, silver maple, white cedars and blue spruce.

Deer—observed directly and by sign (including tracks, scat and a deer mandible)—were abundant in this area. No other mammals, and no amphibians or reptiles, were observed, although in the fall, numerous American toads could be heard. Bird species observed in Area 7 are listed in Table 7.

Butterflies seen in this area included the clouded sulfur (*colias philodice*), monarch *(Danaus plexippus),* black swallowtail (*Papilio polyxenes*), cabbage white and common wood nymph (*Cercyonis pegala*).

Table 7: Birds Identified in Area 7, Vicinity of Nuclear Road

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Red-winged Blackbird	*Agelaius phoeniceus*	X	X	X	
Le Conte's Sparrow	*Ammodramus leconteii*			X	
Mallard	*Anas platyrhynchos*	X			
Cedar Waxwing	*Bombycilla cedrorum*		X		
Canada Goose	*Branta canadensis*			X	X
Red-tailed Hawk	*Buteo jamaicensis*		X		
American Goldfinch	*Carduelis tristus*	X	X	X	
American Crow	*Corvus brachyrhynchos*		X	X	X
Yellow-rumped Warbler	*Dendroica coronata*			X	
Palm Warbler	*Dendroica palmarum*			X	
Yellow Warbler	*Dendroica petechia*			X	
Bobolink	*Dolichonyx oryzivorus*	X	X		

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Gray Catbird	*Dumetella carolinensis*			X	
American Kestrel	*Falco sparverius*		X		
Barn Swallow	*Hirundo rustica*		X		
Dark-eyed Junco	*Junco hyemalis*			X	
Herring Gull	*Larus argentatus*	X			
Wild Turkey	*Meleagris gallopavo*		X		
Song Sparrow	*Melospiza melodia*		X	X	
Brown-headed Cowbird	*Molothrus ater*	X			
Ring-necked Pheasant	*Phasianus colchicus*		X	X	
Downy Woodpecker	*Picoides pubescens*			X	
Pine Grosbeak	*Pinicola enucleator*		X		
Black-capped Chickadee	*Poecile atricapillus*			X	
Golden-crowned Kinglet	*Regulus satrapa*			X	
American Tree Sparrow	*Spizella arborea*			X	
Clay-colored sparrow	*Spizella pallida*	X	X		
Field Sparrow	*Spizella pusilla*			X	
Meadowlark	*Sturnella sp.*	X	X	X	
European Starling	*Sturnus vulgaris*		X		
Tree Swallow	*Tachycineta bicolor*	X	X		
Carolina Wren	*Thryothorus ludovicianus*		X		
American Robin	*Turdus migratorius*		X		
Mourning Dove	*Zenaida macroura*		X	X	
White-throated Sparrow	*Zonotrichia albicollis*			X	
White-crowned Sparrow	*Zonotrichia leucophrys*			X	

3.8 AREA 8: SOUTHERN LEASED LAND

This area is bordered on the west and south by the site property line; on the east by State Route 42; and on the north by the southern extent of Area 7. This entire area is leased to local farmers. The only portion of this area not cultivated is a small wooded area along an access road, to the south of the School Forest parking lot. One tract of approximately 20 acres, across the road from the parking lot, had not been tilled during the spring or summer surveys. It consisted primarily of grasses and white sweet-clover, along with dandelions and some ox-eye daisy. Birds in this field consisted almost exclusively of red-winged blackbird and barn swallows.

The wooded area discussed above is less than one acre, and consists primarily of ash trees, some of considerable size. Groundcover is primarily jewelweed. The access road that provides egress to this woodland is lined with small, single trees, alternating between red osier dogwood, ash and black cherry.

Mammal sign included deer and raccoon tracks, and the scat of an unidentified predator. Few birds were observed during the spring survey, possibly because of the fact that most of the land was recently tilled, and because of an approaching severe storm when a portion of the survey was conducted. More were observed in the summer and fall surveys. These are identified in Table 8 below.

Butterflies seen in this area included the clouded sulfur (*colias philodice*) and monarch *(Danaus plexippus)*.

Table 8: Birds Identified in Area 8, Southern Leased Land

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Red-winged Blackbird	*Agelaius phoeniceus*	X	X		
Mallard	*Anas platyrhynchos*	X			
Canada Goose	*Branta canadensis*				X
American Goldfinch	*Carduelis tristus*		X	X	
Purple Finch	*Carpodacus purpureus*		X		
Northern Harrier	*Circus cyaneus*			X	
Rock Dove	*Columba livia*		X		
Eastern Wood-Pewee	*Contopus cooperi*		X		
American Crow	*Corvus brachyrhynchos*			X	
Barn Swallow	*Hirundo rustica*	X			
Wood Thrush	*Hylocichla mustelina*			X	
Dark-eyed Junco	*Junco hyemalis*			X	
Song Sparrow	*Melospiza melodia*		X	X	
Indigo Bunting	*Passerina cyanea*		X		
Ring-necked Pheasant	*Phasianus colchicus*				X
Downy Woodpecker	*Picoides pubescens*			X	
Golden-crowned Kinglet	*Regulus satrapa*			X	
Clay-colored sparrow	*Spizella pallida*		X		
American Robin	*Turdus migratorius*		X		

3.9 SUMMARY

The KPS site contains a diversity of habitat types, ranging from farmland, to open fields, to woodland, to lakeshore. The habitats contain diverse vegetation, most of which can provide either food or shelter for numerous species of fauna. The species are enumerated in each section above.

The summary table of birds below not only summarizes the species present, but also provides a subjective sense for which species were seen most often. In the table, an "O" (Observed) means the species was observed, but less than 20 times during that season's survey. A "C" (Common) means the species was observed between 20 and 40 times. An "A" (Abundant) means it was observed more than 40 times.

Table 9: Summary Table of Birds Observed During Spring, Summer and Fall Surveys

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Spotted Sandpiper	*Actitis macularia*	O	O	O	
Red-winged Blackbird	*Agelaius phoeniceus*	A	A	O	
Le Conte's Sparrow	*Ammodramus leconteii*			O	
American Wigeon	*Anas americana*				O
Blue-winged Teal	*Anas discors*	O			
Mallard	*Anas platyrhynchos*	C	A	A	A
Black Duck	*Anas rubripes*				O
Gadwall	*Anas strepera*	C	O		
Greater White-fronted Goose	*Anser albifrons*				O
Ruby-throated Hummingbird	*Archilochus colubris*		O		
Great Blue Heron	*Ardea herodias*	O	C	O	
Short-eared Owl	*Asio flammeus*				O
Redhead	*Aythya americana*			O	O
Cedar Waxwing	*Bombycilla cedrorum*		A	C	O
Canada Goose	*Branta canadensis*	C	O	A	A
Great Horned Owl	*Bubo virginianus*	O	O	O	
Bufflehead	*Bucephala albeola*	O			A
Common Goldeneye	*Bucephala clangula*		O		A
Red-tailed Hawk	*Buteo jamaicensis*		O	O	O
Green Heron	*Butorides virescens*	O			
Northern Cardinal	*Cardinalis cardinalis*	C	C	O	O

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Pine Siskin	*Carduelis pinus*	O			
American Goldfinch	*Carduelis tristus*	A	A	A	A
House Finch	*Carpodacus mexicanus*	O			O
Purple Finch	*Carpodacus purpureus*	O	O		
Turkey Vulture	*Cathartes aura*	O		O	
Veery	*Catharus fuscescens*	O			
Hermit Thrush	*Catharus guttatus*	O		O	
Brown Creeper	*Certhia americana*			O	
Belted Kingfisher	*Ceryle alcyon*	O	O		
Chimney Swift	*Chaetura pelagica*		O	O	
Killdeer	*Charadrius vociferus*	O	O	O	
Northern Harrier	*Circus cyaneus*	O		O	
Northern Flicker	*Colaptes auratus*	O	O	C	
Rock Dove (Pigeon)	*Columbia livia*	O	O	O	O
Eastern Wood-Pewee	*Contopus cooperi*		O	O	
American Crow	*Corvus brachyrhynchos*	C	A	C	C
Blue Jay	*Cyanocitta cristata*	O	O	O	O
Yellow-rumped Warbler	*Dendroica coronata*	O		A	
Magnolia Warbler	*Dendroica magnolia*	O			
Palm Warbler	*Dendroica palmarum*	O		C	
Chestnut-sided Warbler	*Dendroica pensylvanica*	O			
Yellow Warbler	*Dendroica petechia*	C	O	O	
Bobolink	*Dolichonyx oryzivorus*	O	O		
Gray Catbird	*Dumetella carolinensis*	C	C	C	
Least Flycatcher	*Empidonax minimus*			O	
Horned Lark	*Eremophila alpestris*	O			
Peregrine Falcon	*Falco peregrinus*	O	O	O	
American Kestrel	*Falco sparverius*		O		
American Coot	*Fulica americana*				O
Common Loon	*Gavia immer*	O			
Common Yellowthroat	*Geothlypis trichas*	O	O	O	
Sandhill Crane	*Grus Canadensis*	O			
Barn Swallow	*Hirundo rustica*	C	C		
Wood Thrush	*Hylocichla mustelina*	O	O	O	
Baltimore Oriole	*Icterus galbula*	O			
Dark-eyed Junco	*Junco hyemalis*			O	C
Herring Gull	*Larus argentatus*	C	A	C	C

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Ring-billed Gull	*Larus delawarensis*	A	A	A	A
Great Black-backed Gull	*Larus marinus*			O	C
Bonaparte's Gull	*Larus philadelphia*	A	O		
Wild Turkey	*Meleagris gallopavo*	O	O	O	C
Swamp Sparrow	*Melospiza georgiana*		O		
Song Sparrow	*Melospiza melodia*	C	C	A	
Red-breasted Merganser	*Mergus serrator*	O			O
Black-and-White Warbler	*Mniotilta varia*	O		O	
Brown-headed Cowbird	*Molothrus ater*	C	C		
Connecticut Warbler	*Oporornis agilis*		O		
Mourning Warbler	*Oporornis philadelphia*			O	
Eastern Screech-Owl	*Otus asio*			O	
Osprey	*Pandion haliaetus*	O			
House Sparrow	*Passer domesticus*	O	O		
Indigo Bunting	*Passerina cyanea*		O		
Cliff Swallow	*Petrochelidon pyrrhonota*	O			
Double-crested Cormorant	*Phalacrocorax auritus*	C			O
Ring-necked Pheasant	*Phasianus colchicus*		O	O	O
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	O	O	O	
Downy Woodpecker	*Picoides pubescens*	O	O	O	O
Three-toed Woodpecker	*Picoides tridactylus*		O	O	
Hairy Woodpecker	*Picoides villosus*			O	
Pine Grosbeak	*Pinicola enucleator*		O		
Snow Bunting	*Plectrophenax nivalis*				O
Black-capped Chickadee	*Poecile atricapillus*	O	C	C	A
Blue-gray Gnatcatcher	*Polioptila caerulea*	O	O	O	
Purple Martin	*Progne subis*		O		
Common Grackle	*Quiscalus quiscula*	C	O		
Golden-crowned Kinglet	*Regulus satrapa*			C	O
Bank Swallow	*Riparia riparia*	C	C		
Eastern Phoebe	*Sayornis phoebe*	O	O	O	
American Woodcock	*Scolopax minor*	O	O	O	
Ovenbird	*Seiurus aurocapillus*	O			
American Redstart	*Setophaga ruticilla*	O	O	O	
Eastern Bluebird	*Sialia sialis*	O	O		
Red-breasted Nuthatch	*Sitta canadensis*	O			O
White-breasted Nuthatch	*Sitta carolinensis*		O	O	O

Common Name	Scientific Name	Spring	Summer	Fall	Winter
Yellow-bellied Sapsucker	*Sphyrapicus varius*			O	
American Tree Sparrow	*Spizella arborea*			O	C
Clay-colored sparrow	*Spizella pallida*	A	A	O	
Chipping Sparrow	*Spizella passerina*	O	O		
Field Sparrow	*Spizella pusilla*			O	
Caspian Tern	*Sterna caspia*	C	O		
Meadowlark	*Sturnella sp.*	O	O	O	
European Starling	*Sturnus vulgaris*	C	A	A	
Northern Hawk Owl	*Surnia ulula*				O
Tree Swallow	*Tachycineta bicolor*	A	C		
Carolina Wren	*Thryothorus ludovicianus*		C		
Brown Thrasher	*Toxostoma rufum*				O
House Wren	*Troglodytes aedon*	C	A		
Winter Wren	*Troglodytes troglodytes*		O		
American Robin	*Turdus migratorius*	C	A	A	
Eastern Kingbird	*Tyrannus tyrannus*	O	O		
Nashville Warbler	*Vermivora ruficapilla*	O			
Philadelphia Vireo	*Vireo philadelphicus*		O		
Blue-headed Vireo	*Vireo solitarius*		O	O	
Canada Warbler	*Wilsonia canadensis*			O	
Mourning Dove	*Zenaida macroura*	C	C	O	
White-throated Sparrow	*Zonotrichia albicollis*	O		A	
White-crowned Sparrow	*Zonotrichia leucophrys*	C		O	

4.0 THREATENED AND ENDANGERED SPECIES

During the conduct of this survey, a particular effort was made to identify the presence, if any, of threatened or endangered species—both state and federal. The Wisconsin Department of Natural Resources website was examined to determine what species might likely be found in the survey area.

All birds that were visible long enough to identify were identified and cross-referenced to the state and federal lists. No listed mammals are known to occur in Kewaunee County. As for reptiles and amphibians, the range of the Blanding's Turtle (*Emydoidea blandingii*) includes Kewaunee County; however, as has been stated throughout the survey report, no reptiles were observed during this survey. Finally, the gastropod cherrystone drop (*Hendersonia occulta*) was also considered, because it is known to occur in Kewaunee County. Efforts were made to determine the presence of this species in all appropriate habitats, and none were found.

Four vascular plants were singled out prior to the survey for consideration. Two—the sand reedgrass (*Calamovilfa longifolia var. magna*) and the forked aster (*Aster furcatus*), both Wisconsin threatened—were chosen because their range includes Kewaunee County. Two others—the dwarf lake iris (*Iris lacustrus*) and dune thistle (*Cirsium pitcheri*), both federally and state threatened—are not known to be found in the County, but do occur in neighboring Door County, and prefer habitat that could exist on site.

As discussed earlier in this report, a particular effort was made to determine the presence of the dwarf lake iris in Area 1, due to its known association with white cedar forests[14]. The spring survey was timed to determine the presence of blooms, if any. None were detected, not only in Area 1, but throughout the site. Efforts to determine their presence continued through the summer and fall surveys, and none were found.

The dune thistle is found in the type of habitat that exists along the site's shoreline. During this survey, no specimens of this plant were found.

The sand reedgrass (*Calamovilfa longifolia var. magna*) flowers from July through September[15]. None were identified during this survey. The forked aster (*Aster furcatus*) blooms beginning in August, making it difficult to identify in the spring and early summer. During the fall survey, a concerted effort was made to determine the presence of this species. As stated above, and as would be expected, asters were found throughout the site during the fall. Wherever asters were seen, they were examined to determine the possibility that they could be forked aster, as shown and described in the Wisconsin Department of Natural Resources (DNR) fact sheet on the species. This species was not found anywhere on site.

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Redacted

Finally, two birds, although they were not observed during this survey, merit discussion. The bald eagle (*Haliaeetus leucocephalus*) is federally listed as a threatened species. Since the banning of the pesticides that caused a dramatic population decline several decades ago, the eagle has made a significant recovery, and is currently under consideration for delisting (It has already been removed from the Wisconsin list).

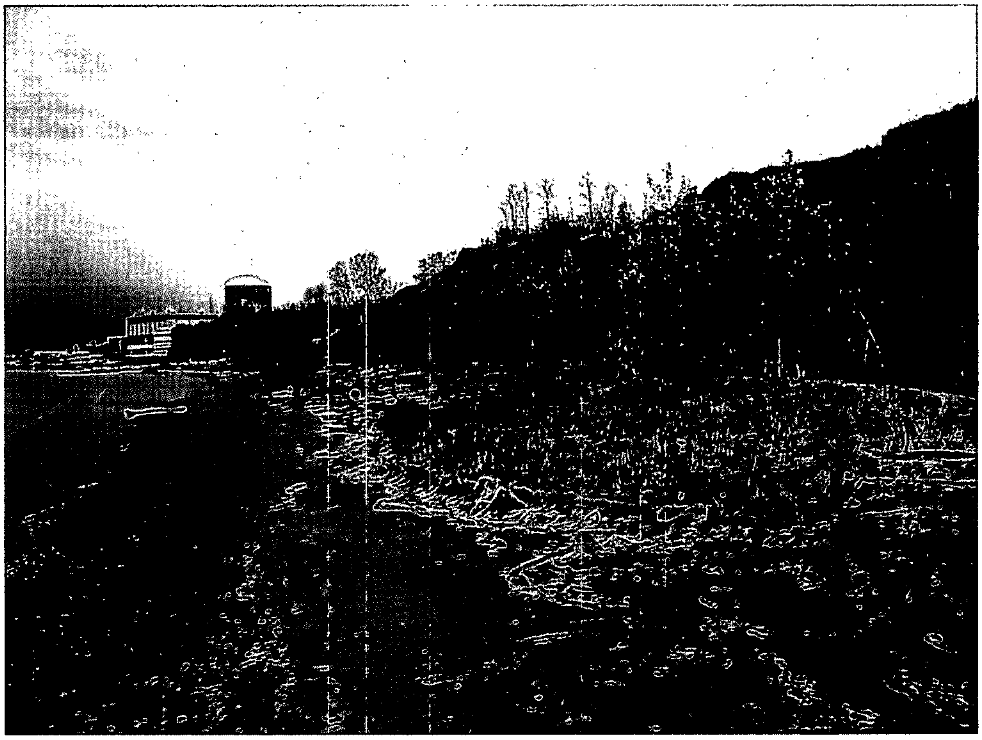
Although no bald eagles were observed during this survey, numerous employees have reported seeing them periodically during the last few years. Because of the sporadic nature of the sightings, it is clear that the eagle is not nesting in the area; however, it is reasonable to believe that they periodically use the area for feeding.

The Great Lakes population of the piping plover (*Charadrius melodus*) is highly endangered. At present, no breeding population is found anywhere along the Wisconsin shoreline of Lake Michigan[16].

In the Great Lakes region, the piping plover begins arriving in late April, and most nests are initiated by mid- to late-May[17]. The spring portion of this survey was specifically timed for this migration, to examine whether or not the plover was present on the KPS shore. Although the species has no known history of breeding in the area, it did at one time breed on the southern Wisconsin shore of the lake[18].

No piping plovers were observed during this survey; however, consistent with a similar effort during the license renewal of the Point Beach station five miles away, the shoreline was surveyed to determine the presence or absence of potential piping plover habitat, should the bird make a sufficient recovery in the future. Piping plovers prefer open, sparsely vegetated sandy habitats for nesting, foraging and rearing young.[20] Studies of nesting sites for Great Lakes piping plovers indicate a preference for stretches of wide beach, with a mean width of 100 feet; however, beach width for nest sites in some studies has varied from as little as 23 feet up to 620 feet.[21]

It is important to note that, as discussed in the Introduction, the presence of habitat for shore-nesting birds is highly dependent on lake water level. Lake Michigan is currently on the low end of its water level cycle, resulting in potential habitat that will disappear if and when lake level increases. Conversely, should lake water level in the future decrease to historically low levels, additional habitat that has not existed in historic times could be created.



LAKE MICHIGAN SHORELINE, TYPICAL OF THE AREA NORTH OF THE KPS PLANT

As discussed in the section on Area 5 above, the site shoreline was surveyed to determine the presence of potential breeding habitat. Consistent with the

"Recovery Plan for the Great Lakes Piping Plover" (U. S. Fish and Wildlife Service, 2003), and the Point Beach survey performed during license renewal,[21] minimum habitat was considered to be present if it contained "a total shoreline length of at least 0.2 km [approximately 220 yards] of gently sloping, sparsely vegetated (<50% herbaceous and low woody cover) sand beach with a total beach area of at least 2 ha [approximately 5 acres]. Appropriately sized sites also must have an area of at least 50 m in length where the beach width is more than 7 m [approximately 23 feet]."[22]

Based on the above criteria, the KPS shoreline, as described in the section on Area 5 above, while, at best, marginal habitat, does meet the minimum criteria for nesting, from the north boundary of the site, to the unnamed intermittent stream immediately south of the plant. The shoreline south of this area is far too narrow to meet even the minimum habitat criteria.

On September 5, 2006, in response to a request for information from the Kewaunee Independent Spent Fuel Storage Facility Installation (ISFSI) project, the DNR sent a letter to Dominion Electric Environmental Services.[23] This letter identified species of potential interest to the DNR. Following discussions with Ken Roller of Dominion Electric Environmental Services, the content of this letter resulted in a special concentration on the area of the ISFSI project, and the species discussed in the letter, during the fall survey.

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The letter also listed seven species—five state SC species and two state Threatened (T) species—that, while they have not historically been recorded in the area, may be found in the habitats described in the ISFSI project area. The letter suggested surveying the area of impact for these species. The species listed are:

- Climbing fumitory (*Adlumia fungosa*) (SC)
- Snow trillium (*Trillium nivale*) (T)
- Christmas fern (*Polystichum acrostichoides*) (SC)
- Indian cucumber root (*Medeola virginiana*) (SC)
- Showy lady's-slipper (*Cypripedium reginae*) (SC)
- Long-spur violet (*Viola rostrata*) (SC)
- Sand reedgrass (*Calamovilfa longifoia* var. *magna*) (T)

During the spring and summer surveys, the ISFSI project area was surveyed in the same manner as the rest of the site. None of the above species were identified during those surveys.

In response to this letter, the fall survey included a concentrated examination of the project area—approximately three hours of field survey time in a relatively small impact area—in an effort to determine the presence or absence of these species. Additionally, the survey of the entire site was performed in a manner to determine if these species are found anywhere on site. None of these species were determined to be on site, either in the ISFSI area, or the site proper.

It is important to note that the snow trillium—which is not listed as occurring in Kewaunee county—blooms in early spring, possibly prior to the conduct of the spring survey, and that above-ground vegetation disappears in the summer. Thus, it was not possible to ascertain the absence of the plant during this survey. The letter suggests an early spring survey.

It is also important to note that the long-spur violet would not be blooming during the fall survey. As stated above, two violets—common blue and downy yellow forest—were found at numerous locations around the site during the spring and summer surveys, and no long-spur violets were found anywhere on site. During the fall survey, a small patch of violet leaves was located in the impact area. Although, based on the survey for the rest of the site, these violets are more likely to be of the common blue or downy yellow forest variety, it was not possible to ascertain the species.

5.0 HISTORIC AND ARCHAEOLOGICAL RESOURCES

Introduction

During the conduct of the habitat survey, the site was surveyed for potential historic/archaeological resources. Prior to the survey, the Kewaunee County Historical Society was contacted for their input. The Kewaunee County Research Center in Algoma, and the County Historical Museum, were also visited.

The result was a focus on three areas: Sandy Bay; the area to the immediate north of the plant site; and the Joe Krofta Memorial Forest. As a general matter, because the site has historically been used for farming, remnants of barbed wire fencing are found nearly throughout the site.

5.1 SANDY BAY

Many years ago, before Europeans settled Kewaunee County, Sandy Bay Creek was considerably larger than it is today. The Potawatomi Indians used to establish a temporary fishing camp here each year during the spawning runs of fish[25].

In 1856, when Kewaunee County was first organized, three towns were established: Wolf River (the northern third of the county), Kewaunee (central) and Sandy Bay, which "included the present limits of Carlton and Franklin. It was named for the little indenture in the shore of Lake Michigan and so known to Lake navigators as an anchorage ground."[26]. Over the next few years, Franklin and Carlton became separate towns, and ultimately, the small area in the vicinity around the northern part of the KPS property became known as Sandy Bay. It is reported that at one time, Sandy Bay was a thriving village, with a productive sawmill (using a dam erected on Fischer Creek), a general store, cheese factory, post office and hotel[27]. For a good part of the late 1800s, a large pier at Sandy Bay was a center for shipping in the area, where lumber, bark (for tanning), and farmers' crops were shipped to Milwaukee and Chicago. By 1891, "the settlement had all but disappeared. D.B. Harrington wrote, 'The other week I rode through the southern Carlton Township and visited Sandy Bay. Once a thriving center of commerce, the pier has rotted away nor is there any store or saloon and the Blue Ribbon Hall is deserted.'"[28]

At the current water level in the Lake, a few of the rotting pilings of the former pier can still be seen from the shoreline. Areas 1 and 2 were carefully surveyed in an effort to locate any additional artifacts of Sandy Bay history. The entire length of Fischer Creek was walked on both sides, in an effort to find any remnants of the old sawmill or dam. None were found. No remnants of any buildings or foundations were located. The streamsides and edges of recently tilled fields were perused for any Native American or historic artifacts that might have recently been unearthed. None were found. Aside from the rotting pilings of the pier, the only evidence of any past human presence in the area is:

- the rusting remains of the rear of an old threshing machine, which may have been from one of the farms abandoned during construction of the plant. This implement is located in the woods just south of where Fischer Creek goes under Sandy Bay Road;
- what appears to be a trash heap associated with a farm, located on the east bank of Sandy Bay Creek, near the cultivated field off of Lakeview Drive (Caution: this area is rather steep); and
- the short stretch of old barbed wire fence previously described in Area 2, north of the wetland, along with other stretches of barbed wire elsewhere in the area.

During Sandy Bay's hayday, the site included St. John's Lutheran Church and cemetery, and the Sandy Bay School. The Church, which was disbanded in 1947[29], was located on Route 42, in the front of the cemetery plot currently owned by the Town of Carlton. There is no evidence remaining of what was the church; however, the cemetery, alternately known as St. John's Lutheran Cemetery and Sandy Bay Cemetery, still exists, and is cared for by the town. Sandy Bay School was located across Route 42 from the church. There is no evidence remaining of the school.

5.2 NORTH OF PLANT SITE

As stated previously, most of the KPS site was farmland prior to construction. Some buildings associated with farms to the north of the plant were torn down during construction. During the planning for the ISFSI project, a Phase 1 archaeological survey was performed on the undisturbed portion of the project area. No artifacts were found in the ISFSI area.

Three artifacts of past activity were found in the general area north of the plant:

- A rusted disc harrow, either from one of the farms abandoned during plant construction or from the creation of the ballfield, lies near the ballfield north of the plant.
- An old bridge, with a round, steel culvert (shown below), was found over the unnamed intermittent stream north of the plant. This bridge was constructed by a farmer who owned the land prior to plant operation. The steel culvert was created from an old boiler, and concrete slabs were placed over the culvert.

- A concrete bridge abutment, over the north intermittent stream, near Route 42, marks where a portion of Lakeview Drive used to travel, prior to its relocation to the north of the stream. In response to an immediate human safety concern because of the severe deterioration of this bridge, it was removed in September of 2006.

5.3 JOE KROFTA MEMORIAL FOREST

As discussed in the Introduction, the Joe Krofta Memorial Forest, south of the plant, was dedicated in 1987 to the former owner of the land, who cared for the forest. When the plant began operation, Krofta's original log cabin was one of the features on the self-guided trail used by students. During the 1980s, however, the lake water level reached historic high levels. Due to the resulting erosion, the cabin was about to collapse into Lake Michigan. The plant's owner at the time was able to salvage the front facade of the cabin and move it to its current location, further away from the shore of the lake.

The front of Joe Krofta's original log cabin was rescued from the ravages of cliff erosion during the 1980s, and was moved inland to its current location.

In addition to that discussed above, another old concrete bridge—likely an old farm bridge—was discovered over the south intermittent stream, several hundred yards downstream of Route 42.

Summary

A few remnants of past human activity were determined to be on site during this site survey. None are of any known historic significance. These artifacts will be discussed with the NRC during the site visit.

6.0 ENDNOTES

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[1] US Atomic Energy Commission, December 1972 (AEC 1972). Final Environmental Statement related to the Operation of Kewaunee Nuclear Power Plant.

[2] Plat, Town of Carlton, T.22 N. - R.24 E Kewaunee County, showing leased areas (T.22 N. – R.24 E)

[3] AEC 1972

[4] Canadian Hydrographic Service Central and Arctic Region, Fluctuations in Lake Levels, accessed on 02/09/2006 at:

http://chswww.bur.dfo.ca/danp/fluctuations_e.html

[5] Ibid

[6] CAD program transmittal from Forrest Kocon, 08/09/2006 (Kocon)

[7] Ibid

[8] Ibid

[9] Wisconsin Public Service Corporation, Fall 1987, Shoreline Newsline, Forest Dedicated: Krofta's Dream Becomes Memorial

[10] Kocon

[11] Ibid

[12] Ibid

[13] Ibid

[14] WDNR fact sheet, accessed prior to 05/08/2006 at:

http://www.dnr.state.wi.us/org/land/er/factsheets/plants/dwarf.htm

[15] WDNR fact sheet, accessed 06/07/2006 at:

http://www.dnr.state.wi.us/org/land/er/factsheets/plants/Sndreed.htm

[16] WDNR fact sheet, accessed 05/31/2006 at:

http://www.dnr.state.wi.us/org/land/er/factsheets/birds/images/map20.gif

[17] WDNR fact sheet, accessed 05/31/2006 at:

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http://dnr.wi.gov/org/land/er/factsheets/birds/PLOVER.HTM

[18] U. S. Fish and Wildlife Service, Recovery Plan for the Great Lakes Piping Plover (*Charadrius melodus*), September 2003

[19] Ibid

[20] Ibid

[21] Ibid

[22] "Piping Plover Habitat on We Energies Property near the Point Beach Nuclear Plant," Dr. Noel Cutright, October 13, 2004. NRC ADAMS Accession No. ML043150318

[23] Ibid

[24] 5 September 2006, State of Wisconsin Department of Natural Resources, "Endangered Resources Review (ERIR Log #06-255), Dominion Energy Kewaunee – Spent Fuel Storage Facility," letter from S. Koslowsky, DNR, to K. Roller, Dominion Resources Services.

[25] Personal communication with Thomas Schuller, president, Kewaunee County Historical Society, 11/30/2005, and 05/12/2006

[26] Kewaunee County web site, Kewaunee History, undated, accessed on 11/10/2005 at:

http://www.kewauneeco.org/subpages/History/history.htm

[27] Kewaunee County Historical Society, March 2002, Background for Historical Markers

[28] Ibid

[29] Historic Archives, accessed 06/01/2006 at:

http://www.rootsweb.com/~wikewaun/cem4.htm

AMERICAN TRANSMISSION COMPANY®	Specification	Department:	Asset Maintenance
		Document No:	SN-0801 v02
Title: **TRANSMISSION LINE RIGHT-OF-WAY VEGETATION MANAGEMENT**		Issue Date:	08-25-2008
		Previous Date:	09-17-2007

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Approved By: Duane Schoon Signed original on file	**Author:** Jim McCabe

CAUTION: Any paper or filed copy of this document should be verified against the record version on an ATC on-line system.

1.0 Scope

1.1 This specification describes utility vegetation management work (hereinafter referred to as the "Services") associated with ATC's electric power transmission line right-of-way corridors.

1.2 The specifications are designed to maintain Contractor vegetation management work in compliance with the ATC Transmission Vegetation Management Program (TVMP) and the requirements of NERC Reliability Standard FAC-003-1, Transmission Vegetation Management Program.

1.3 ATC's present work plan is to maintain the transmission line right-of-ways approximately every three (3) years in densely populated areas, and approximately every five (5) years in other areas.

2.0 General

2.1 Contractor Requirements

2.1.1 Contractor shall furnish supervision, labor, tools, equipment, report forms, maintenance vehicular equipment, transportation and material necessary for the transmission line right-of-way vegetation management. ATC will furnish copies of the necessary maps for identifying the locations of the transmission lines for which right-of-way clearance is required. ATC will furnish copies of this specification upon request.

2.1.2 Contractor must comply with all provisions in this Transmission Line Right-of- Way Clearing Specification #SN-0801, and the most current revision of ANSI Z 133.1 "Safety Requirements for Arboricultural Operations"..

2.1.3 Contractor is required to have experience in electric utility transmission line right-of-way vegetation management. Upon request, Contractor shall provide the names and addresses of at least 4 references for which this type of work has been performed.

2.1.4 Contractor must comply with all laws and regulations, take all necessary precautions to protect the safety of employees and to prevent accidents or injury to persons on, about, or adjacent to the premises where the Services are being performed. Contractor must comply with all applicable provisions including but not limited to Federal, State, and local laws and regulations including, but not limited to, Environmental Protection Agency (EPA), Occupational Safety & Health Administration (OSHA), Department of Natural Resources (DNR) and Department of Transportation (DOT) regulations.

2.1.5 Contractor shall provide ATC with 24-hour emergency call-out assistance throughout the entire year. Contractor must be capable of providing sufficient resources for emergency response.

2.1.6 Contractor's personnel will observe ATC facilities in the vicinity where Services are performed. Any facility anomalies observed, including but not limited to broken, loose or worn poles, wires or structures shall be reported to the ATC Transmission Line Maintenance Specialist. Anomalies that would appear to pose a threat to persons, property or the electric transmission system shall be reported by telephone immediately to the ATC Transmission Line Maintenance Specialist. Anomalies that do not appear to pose a threat to persons, property or the electric transmission system shall be reported in Contractor's Right-of-Way Progress Report.

2.1.7 Contractor personnel shall abide by terms and conditions of ATC's Karner Blue Habitat Conservation Plan. The plan can be obtained through the ATC Environmental Department.

2.1.8 For projects located in Milwaukee, Waukesha, Washington, and Ozaukee counties, the contractor shall contact the ATC Environmental Department for information regarding possible impacts to Butler's Garter Snake and any necessary restrictions to minimize those impacts.

2.2 Personnel Qualifications

2.2.1 Personnel assigned to perform utility right-of-way vegetation management maintenance and forestry services for ATC must be "Qualified Personnel," "Qualified Line-Clearance Arborists, or "Qualified Line-Clearance Arborist Trainees" as required to perform the Services and as defined in ANSI Z133.1. Personnel shall be instructed and shall follow provisions in ANSI Z133.1 relative to work performed in proximity to electrical lines and the associated hazards. Staffing shall be consistent with such standard.

2.2.2 Supervision of Services shall be performed using Qualified Personnel as defined in ANSI Z133.1, who are full-time supervisors with at least 2 years of field experience in vegetation management for transmission line right-of-way.

2.3 Permits

2.3.1 Contractor shall be responsible for obtaining licenses and permits necessary for the performance of the Services.

2.4 Right-of-Way Rights, Access and Obstructions

2.4.1 Contractor shall confirm easement and license rights prior to performing Services. Contractor shall not use lands beyond easement or license boundaries for any purpose, including ingress or egress, without the consent of the landowner. Landowner consent shall be documented.

2.4.2 Contractor shall determine the best means of access to the site. Existing roads are to be utilized for access whenever possible. Use of private roads and off right-of-way access requires the consent of the property owner. Contractor shall not negotiate a fee of any kind for access to existing right-of-way. Contractor is responsible for damages to public and private roads and properties, including damage to crops and fences.

2.4.3 Contractor shall limit vehicular and equipment travel within the right-of-way strip and to as narrow a passageway as practicable.

2.4.4 Contractor shall take necessary precautions to avoid damage to plantings and visual screens, and if possible, use adjacent vacant property over which the easement extends for access to sites.

2.4.5 When a waterway/wetland crossing is necessary, Contractor shall use established crossings of the waterway. Contractor shall not disturb the existing waterway channels or shorelines. If the use of motorized vehicular equipment to cross a waterway/wetland without an established and approved crossing cannot be avoided, Contractor shall work with ATC Environmental staff to obtain permits in advance. Contractor shall provide notice to the Transmission Line Maintenance Specialist prior to proceeding.

2.4.6 Contractor shall close or replace fences it opens or removes during performance of the Services.

2.5 Workmanship and Damages

2.5.1 All work shall be performed in a workmanlike manner, in accordance with this specification and all applicable Federal, State and local laws and regulations. Contractor shall at all times exercise care to prevent injury to any persons and property.

2.5.2 Contractor shall be responsible for all damages to persons, and restoration of property caused during the performance of the Services.

2.5.3 Contractor must repair and restore to their original condition, any fences that have been taken down and roadways that have been used to provide access to a work site.

2.6 Controversies

2.6.1 Controversies arising between property owners and Contractor shall be promptly referred to the appropriate ATC Transmission Line Maintenance Specialist. Controversial Services shall not be performed until the controversy is resolved to ATC's satisfaction.

2.7 Settlement of Damage Claims

2.7.1 Contractor is responsible for all damages caused while performing Services. Damage may include, but is not limited to adverse effects to crops, fences, lands, roads, driveways, culverts, drain tiles, woodlands, buildings and livestock. Contractor shall bear all expenses in the resolution of such claims. Contractor must notify the ATC Transmission Line Maintenance Specialist of any and all claims brought by the property owners within one (1) business day.

2.7.2 Contractor shall keep a record detailing all claims, damages and settlements, and provide the ATC Transmission Line Maintenance Specialist with a written report promptly upon completion of each settlement.

2.7.3 In the event that Contractor and the property owner are unable to resolve any complaint or controversy, ATC may, at its sole option and discretion, proceed to resolve the complaint or controversy. Any such resolution shall be binding upon the Contractor, and costs and expenses incurred by ATC in such resolution may be deducted from amounts owed to Contractor by ATC.

2.8 Quality Control

2.8.1 Contractor's field supervisors shall personally inspect a minimum of 15% of completed Services each reporting period. Inspections shall provide a representative sample encompassing all Contractor crews. The Contractor's Right-of-Way Progress Report shall include:

- The actual inspection percentage for the reporting period.
- The percentage basis (e.g. spans, miles, man-hours)
- Designations of the transmission line segments inspected.
- A statement indicating inspection results in terms of completed Services meeting this specification (e.g. fully meet specification, meet specification with specified exceptions, partially meet specifications).

2.8.2 ATC performs follow-up quality control checks via periodic walking and aerial inspections

2.9 Rights-of-Way Clearing Widths

2.9.1 Contractor shall confirm the width of all easement and license rights prior to performing any Services. Contractor shall contact the ATC Real Estate Department and request copies of the necessary easement and license documents for the right-of-ways scheduled for Services. Contractor must allow 60-days for the ATC Real Estate Department to provide the complete set of easement documents.

2.10 ATC shall advise of known unrecorded special conditions.

2.11 Contractor shall consult with the ATC Transmission Line Maintenance Specialist for instructions if no easement width is specified, no easement document can be located or the ROW easement provides for a larger area than has previously been maintained.

3.0 Notifications

3.1 General

3.1.1 Contractor shall comply with all notice provisions contained in applicable statutes, regulations and ordinances including but not limited to Wis. Adm. Code sec. PSC 1 13.051 0.

3.2 Property Owner

3.2.1 For trimming, mowing, cutting and removal operations, Contractor shall notify property owners of Services to be performed which affects their property. Where permitted by Wis. Adm. Code sec. PSC 113.0510, verbal notification for clearing is sufficient. When property owners are unavailable, door tags/cards supplied by ATC shall be used to notify property owners of intended Services, and to provide property owners with contact information. Any Services performed without notice must have the appropriate ATC Transmission Line Maintenance Specialist's prior approval. Notification of intent to perform Services (but not written approval) may be given to a caretaker or other individual designated as responsible by the property owner.

3.2.2 In addition to all other provisions in this section 3.1, Contractor must obtain approval from property owners prior to herbicide application.

3.2.3 Where the property owner is a state or federal agency the Contractor shall notify the ATC Environmental Department prior to herbicide application. The ATC Environmental department is to work with the Contractor on agency contacts.

3.2.4 Contractor must provide a contact name and telephone number on the door tags/cards, identifying a representative who will be available for evening hour callbacks from property owners.

3.2.5 Property owner notification contacts shall be recorded by the Contractor in Cascade.

3.3 System Operations

3.3.1 Each Contractor crew shall inform the appropriate System Operating Office of the line designation and location they will be working. The Maintenance Specialist shall specify the required reporting frequency and provide telephone numbers for ATC System Operations Pewaukee and ATC System Operations Cottage Grove.

3.3.2 Contractor shall also provide the system Operating Office with a cell phone number with which each crew can be reached at all times.

3.3.3 Contractor shall inspect sites where Services are to be performed prior to beginning each Service. Provisions contained in ANSI Z133.1 relative to working in proximity to electrical hazards shall be observed. The minimum approach distances set forth in Table 1 of ANSI Z133.1 shall be observed at all times. Approach distances shall apply to workers, their equipment, and the vegetation to be removed. In the event Contractor believes that it will be unable to perform the Services while maintaining the clearances set forth in Table 1, Contractor shall so inform the ATC Transmission Line Maintenance Specialist, and shall further contact the closest ATC System Operations Center at the numbers listed above, and request an outage while Services are being performed. In the event that an outage cannot be allowed at that time, the Services shall be suspended and not performed until an outage is available.

3.3.4 ATC System Operating declaration of a Red Alert Status is a notice that immediate threats to transmission lines are to be minimized. The Contractor shall provide ATC with a single point of contact to expedite forwarding of ATC System Operating Red Alert notices. In the event that ATC System Operating declares a Red Alert Status, ATC System Operating will notify the Contractor single point of contact. This Contractor contact is to immediately advise all vegetation management crews to modify work plans such that, only clearing with no risk of accidental outage may continue. ATC System operating will advise the single point of contact when Red Alert Status has been discontinued.

4.0 Scheduling of Work

4.1 General

4.1.1 Contractor shall notify the appropriate ATC Transmission Line Maintenance Specialist of the planned start date ten (10) working days prior to beginning new Services. The notice shall include information on the crew size, working hours and all equipment to be used in performance of the Services.

4.1.2 Contractor shall notify the appropriate ATC Transmission Line Maintenance Specialist at the end of each week where the forestry crews will be starting work the following week. More frequent notifications shall be made if requested by the ATC Transmission Line Maintenance Specialist.

5.0 Integrated Vegetation Management Techniques

5.1 General

5.1.1 Transmission Line Right-of-way clearance shall be based upon an integrated vegetation management philosophy in which alternative maintenance techniques are considered and selected on the basis of the technique or combination of techniques best calculated to achieve cost effective long-term control or elimination of Undesirable Species while encouraging and enhancing the growth of Desirable Species. Refer to the flowchart diagram illustrated in Appendix B.

5.2 Definitions

5.2.1 Integrated Vegetative Maintenance (IVM) - Options include three groups of treatments: physical, chemical, and ecological. These treatment options shall be combined to produce the most cost effective long-term increase in growth of Desirable Species and decrease in Undesirable Species on ATC rights-of-way.

5.2.2 Undesirable Species - Vegetative growth capable of exceeding fifteen (15) feet in height at maturity, which is likely to grow to come in contact with energized conductors or which interferes with access to transmission facilities. (See, Appendix A)

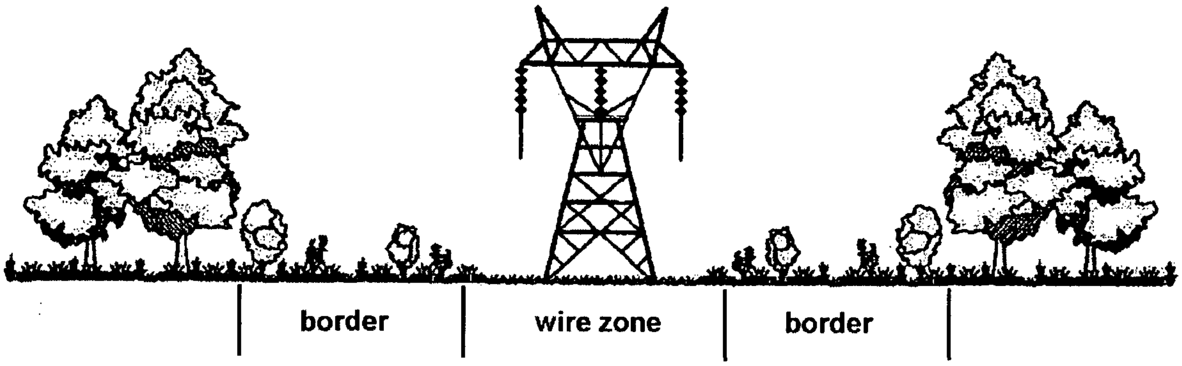
5.2.3 Desirable Species - Vegetation, which does not unreasonably interfere with the operation, maintenance or access to overhead electric lines, structures or facilities. (See, Appendix A)

5.2.4 Invasive Species - Rapidly spreading, undesirable species as designated from time to time by the Wisconsin Department of Natural Resources. Refer to Appendix A .

5.2.5 Wire Zone - Right-of-way located within the transmission line corridor with the boundary extremities located in between the area directly beneath the location of the outer most conductors being supported. Desirable species in this location are low growing forbs, grasses, or crops that will not interfere with access and are located away from poles and other support structures. Note: Undesirable Species and Invasive Species are to be removed from the "Wire Zone". See Figure 1 below, Illustration of Wire Zone and Border Zone on a Transmission ROW.

5.2.6 Border Zone - Right-of-way located between the wire zone extremities and the edge of the right-of-way described within the easement or license. Desirable Species in the border zone are short growing woody species such as shrubs and low trees or forbs and grasses which do not interfere with access and are located away from poles and other support structures. Note: Undesirable Species, and "tall growing"- Invasive Species are to be removed from the "Border Zone". See Figure 1 below, Illustration of Wire Zone and Border Zone on a Transmission ROW.

Figure 1 – Wire Zone and Border Zone on ROW



5.2.7 Selective Hand Cutting - A physical treatment option by which Undesirable Species are removed using hand or chain saws. Selective Hand Cutting shall be required where the low density of Undesirable Species makes the use of herbicides or mowing impractical.

5.2.8 Mowing - A physical treatment option which Undesirable Species are cut with mechanical equipment. Mowing is permitted for relatively flat areas with high densities of Undesirable Species. When mowing is necessary in a wetland, all appropriate permits must be obtained.

5.2.9 Chemical Right-of-way Treatment - Chemical herbicidal application to control Undesirable Species.

5.2.10 Broadcast Foliar Application - A chemical treatment option in which a herbicide is applied to canopies of Undesirable Species. Permitted broadcast application consists of the use of a spray device to apply a low-volume herbicide mixture to target the Undesirable Species with a minimal amount of the herbicide reaching the Desirable Species.

5.2.11 Broadcast Soil-active Application - A chemical treatment option in which a herbicide is broadly applied, generally following Mowing to control the regrowth of Undesirable Species.

5.2.12 Selective Foliar Application - A chemical treatment option in which the herbicide is applied to actively growing individual stems or clumps of Undesirable Species. This treatment avoids or minimizes damage to Desirable Species.

5.2.13 Basal Application - A chemical treatment option in which herbicides are applied to the lower portion, or base of individual Undesirable Species. Basal treatments are generally used in urban areas, near sensitive crops or environmentally sensitive areas or where dormant application is most practicable.

5.2.14 Cut Stump Treatments - A chemical treatment option in which Undesirable Species stumps are treated within 1/2-hour after cutting by application of a herbicide to the cut area.

5.3 Selective Hand Cutting

5.3.1 Selective Hand Cutting shall be required where the low density of Undesirable Species makes the use of herbicides or mowing impractical. Stems or trunks of species capable of obtaining a mature height of fifteen (15) feet shall be completely severed from the root system at a point not more than 4 inches above the ground line. Undesirable Species over six (6) feet tall shall be cut & Cut Stump Treated over the entire length and width of the right-of-way.

5.3.2 Subject to specific easement restrictions, a (15) foot route in the center of the Wire Zone along the entire length of the right-of-way, and a fifteen (15)-foot distance around each pole shall be cleared and treated for Undesirable Species. The 15-foot distance around each pole shall be reduced as required for narrower easements. Undesirable Species less than six (6) feet in height may either be Chemically Treated or Cut Stump treated.

5.3.3 Vines within fifteen (15) feet of the structure, or guys and anchors shall be trimmed or removed and treated. Brush or trees within six (6) feet of the structure, or guys and anchors shall be trimmed or removed and treated.

5.3.4 Areas involving tag alder and willow shall be cleared to a distance of 6 feet beyond the wire zone.

5.3.5 Where Chemical Right-of-way Treatment is prohibited or not allowed under easement conditions, Undesirable Species, regardless of height, shall be cut or mowed.

5.3.6 Trees with trunks located outside of the easement corridor, but which have branches or growth protruding into the easement corridor, shall be side trimmed to the easement line. Where the property owner permits removal of the tree is preferred. Otherwise where the property owner permits the Contractor shall trim the branches protruding into the easement corridor back to the trunk.

5.3.7 Selective hand cutting shall be required within 50' of a stream, river or waterway. Desirable species shall be left where appropriate to mitigate erosion in these 50' zones (see appendix A for a list of desirable species).

5.3.8 Selective hand cutting shall be required in areas identified by the ATC Environmental department staff as environmentally sensitive.

5.4 Disposal of Hand Cut Materials

5.4.1 Vegetative material from trimming or cutting activities shall be disposed of in one of the manners described below. If no disposal technique is specified by the property owner, the cut material shall be disposed of by windrow/pile, lop and scatter, or chipping. NOTE: Regardless of type of disposal, a 15-foot access route free of cut material that could impair access to the transmission line facilities shall be maintained down the length of the right-of-way and to include a 15-foot distance around each structure adjusted to less than the 15-foot requirement around the structure if easement rights do not permit a 15-foot distance.

5.4.2 Windrow/Pile - Cut material shall be piled in large piles or windrows at the edge of the right-of-way. Piles shall not exceed 3 feet in height. A 15-foot break shall be provided in the pile every 75 feet. The number of individual piles shall be kept to a minimum.

5.4.3 Lop and Scatter - Cut material shall be delimbed and cut to lay in close contact with the ground.

5.4.4 Chipping - Cut material shall be chipped . Chips may be blown on site unless specific removal instructions are specified. Chip depths shall not be concentrated to depths of greater than 4 inches but should be spread over the entire site. Vegetation cut in wetland areas will be removed from the wetland and disposed in upland areas or offsite.

5.4.5 Disposal Precautions - The following precautions apply to all disposal operations:

- No cut material including chips shall enter any stream or watercourse.
- No cut material shall be disposed of in access roads, snowmobile trails, agricultural fields or maintained lawn areas.
- No Black Cherry (Prunus Scrotina) or Black Walnut (Juglans nigra) cut during the actual growing season shall be disposed of within an active pasture. Note: The foliage is poisonous to cattle.
- If equipment is used to form windrows/piles, care should be taken to avoid excess soil disturbances. The windrow/piles shall have sufficient openings or breaks to allow for wildlife movement and access by maintenance equipment.

- Cut material shall be kept well back from roads and streams, approximately 100 ft. or out of sight.

5.5 Mowing

5.5.1 Contractor is required to obtain permission from property owners prior to mowing operations on the Right of Way.

5.5.2 Contractor shall enter Cascade MxOrders during mowing operations for required follow-up herbicide applications. Refer to sections 5.0 and 6.0 for herbicide application guidelines.

5.5.3 Contractor shall only utilize mowing equipment when economically justifiable.

5.5.4 Prior to commencing mowing activities within ATC transmission line right-of-way, the Contractor must obtain necessary permits.

5.5.5 Soil disturbance should be minimized; no grubbing of root systems is permitted. The goal is to minimize the amount of soil disturbance to prevent creating areas where soil erosion could occur.

5.5.6 No wetlands, streams or waterways are to be crossed with the mowing equipment except over existing bridges or culverts unless necessary permits are obtained.

5.5.7 Work may proceed to a point 50' from the edge of a stream, river or waterway. Mowing is not permitted within a 50' zone either side of the waterway. These areas are restricted to hand clearing.

5.6 Broadcast Foliar Application

5.6.1 The preferred broadcast method is through the use of a Radiarc®, or equivalent, spray device to apply a low-volume herbicide mixture. The application shall minimize the amount of herbicide that reaches the ground and affects Desirable Species. Broadcast Foliar applications may be used with chemically selective or non-selective herbicide products. Methods for Broadcast Foliar Application can include tractor-mounted boom sprayers, tractor-mounted Radiarc® boomless sprayers, or hose-end spray guns.

5.6.2 Broadcast Foliar Application may be used in areas with a high density of woody Undesirable Species, where vehicular traffic is permitted and with the permission of landowners. Broadcast Foliar Application should not be used on right-of-ways in urban areas, adjacent to croplands or near sensitive habitats.

5.7 Broadcast Soil-Active Application

5.7.1 Soil surface applied herbicides that control broadleaved Undesirable Species by taking the chemical up through the roots may be used only if the treatment will not damage grasses in the area. This type of application shall also not be used on frozen ground.

5.7.2 Contractor shall avoid affecting trees that may have roots extending into the treatment area.

5.8 Selective Foliar Application

5.8.1 Application may use either a backpack or truck-mounted sprayer to deliver herbicide on individual stems or clumps of actively growing Undesirable Species. This low-volume approach shall be used on vegetation under 8 feet in height. A high volume foliar application can be used for taller Undesirable Species. Another acceptable alternative is to mow the right-of-way so that a low-volume approach can be used in the following growing season. The low volume foliar technique is more selective than broadcast applications because less coverage is required to control individual plants, minimizing potential overspray.

5.8.2 Low-volume foliar applications are to be used in suburban areas or where otherwise required by landowners, and may be used in areas with low stem density. Low-volume foliar application shall be completed in late summer to minimize brownout.

5.9 Selective Basal Application

5.9.1 Selective basal applications shall be made using the following procedures:

5.9.1.1 Low Volume Basal

For Undesirable tree Species, the low volume herbicide mixture shall be applied to the basal portion of the stem/trunk including the root collar to a height of 6 to 18 inches above the ground line depending on stem/trunk diameter. (The rule of thumb should be that on stems of less than 3 1/4-inch diameter, the stem/trunk should be treated from the ground line up 6 to 10 inches; stems that are 3 1/4 inch to 1/2-inch diameter should be treated from the ground line up 10 to 18 inches.)

5.9.1.2 Low Volume Basal Banding

For Undesirable tree Species, the low volume herbicide mixture shall be applied to the basal portion of the stern/trunk no higher than 3 feet on the stern/trunk with a bandwidth of 6 to 18 inches depending on stem/trunk diameter. (The rule of thumb should be that on stems/trunks of less than 3/4-inch diameter, the stem/trunk should be banded 6 to 10 inches in width; stems that are 3/4 inch to 1-1/2-inch diameter should be banded 10 inches to 18 inches in width. Larger diameter stems shall be Cut Stump Treated.)

5.9.2 The low volume herbicide mixture application shall be applied using either a backpack or canister sprayer equipped with a special low volume basal wand (Example: B and G Extenda-ban drip-proof extension valve with Y-2 tip, or equivalent). The nozzle shall be adjusted to produce a fine-coarse mist. A fog or solid stream pattern should not be used. In no case will leaking equipment be tolerated.

5.9.3 Herbicide Application shall not occur when precipitation is sufficient to render the application ineffective.

5.9.4 Undesirable Species stems less than 6 feet tall shall be treated with a herbicide.

5.10 Cut Stump Treatment

5.10.1 Chemical application to cut stumps shall be made within one-half hour, with immediate application strongly recommended. The herbicide should be applied specifically to the cambium layer (just inside the bark) of the freshly cut stump.

5.10.2 A Low Volume formulation is also an acceptable Cut Stump Treatment. In this treatment, the chemical should be applied to completely wet the bark and root crown.

5.10.3 Application shall not occur when precipitation will dilute and undermine the effectiveness of the chemical.

6.0 General Requirements and Precautions for Herbicide Application

6.1 General Restrictions and Requirements

6.1.1 Herbicides shall not be used without the express consent of the landowner.

6.1.2 Herbicides shall be handled and applied in a manner that will prevent damage to Desirable Species and property. Contractor may use only herbicides registered by the Environmental Protection Agency and the appropriate State Department of Agriculture for the intended use.

6.1.3 Any container in which a herbicide is stored shall be securely locked or bolted to vehicles on the right-of-way and kept locked when left unattended. Empty herbicide containers shall be removed from the right-of-way and kept in a locked compartment until properly disposed. Disposal of herbicides and their containers shall be in accordance with the rules and regulations of all appropriate Federal and State agencies.

6.1.4 Herbicides shall be applied only by properly qualified, certified & licensed applicators. Contractor shall be responsible for the accurate recording and submitting of herbicide usage forms required by any regulatory agency and for complying with all applicable Federal, State and local rules and regulations.

6.1.5 Contractor shall comply with OSHA Hazard Communication requirements and comply with requirements to have in its possession copies of the herbicide labels for each herbicide being used. The labels shall list the herbicide composition, description, directions for use, precautionary statements, warnings, environmental hazards, practical treatments, storage and disposal instructions and any other relevant information about the herbicide being applied. Upon request, the labels as well as the material safety data sheets (MSDS) must be shown to anyone desiring this information.

6.1.6 Contractor shall provide hazard communication and safety programs in compliance with OSHA and other applicable laws and regulations. The communication and programs shall address the purpose of using herbicides, material safety data sheets and product labels, protective safety equipment and clothing and product information. An appropriate safety manual and program is to be provided and utilized by Contractor and its employees.

6.2 Restrictions to Chemical Use

6.2.1 Specific conditions in which herbicide applications are not to be made are as follows:

- Where prohibited by the manufacturer and supplier.
- Where a property owner has not consented to the application.
- Within a wetland, marshy site, or near a stream unless label instructions allow, and property owner has consented in writing.
- Within a vegetable garden

6.3 Spill Prevention

6.3.1 Herbicide spills shall be immediately cleaned up in compliance with industry best practices, manufacturer's instructions, and all Federal, State and local laws and regulations.

6.3.2 Contractor shall provide each crew with a spill kit containing sufficient materials for cleaning up and neutralizing potential spills of herbicides.

6.3.3 Contractor shall be responsible for all clean-up costs associated with providing herbicide application Services to ATC. Contractor must notify the ATC Transmission Line Maintenance Specialist of any and all spills within twenty-four (24) hours.

6.3.4 Contractor shall keep a record of all spills and complete information regarding the clean-up effort, and provide the appropriate ATC Transmission Line Maintenance Specialist with a written report of this information promptly upon completion of any spill clean-up.

6.3.5 Contractor shall forward reports of spills and related cleanup information to the ATC Environmental Department for their records.

6.4 Proper Equipment

6.4.1 Contractor shall supply each herbicide application crew member with all required EPA equipment.

6.4.2 Contractor shall provide vehicles that have adequate covers and locks to comply with Federal and State DOT regulations, in which to store and transport the herbicides.

7.0 Trimming Procedures

7.1 General

7.1.1 Where there is no specified right-of-way width, the following clearances are desired at the time of clearing:

Clearances between vegetation and transmission conductors

Nominal Voltage (kV phase to phase)	Desired Clearance Min (feet - inch)
69kV	20' 9"
115kV	22' 4"
138kV	23' 2"
161kV	24' 0"
230kV	26' 5"
345kV	30' 5"

  - NOTE: Where distribution underbuild is present, the required vertical clearance for distribution circuits shall be as defined in section 7.5.

- Branch Cuts are to be made back to the main stem or to a branch using directional lateral trimming.
- A minimum number of cuts to tree branches should be made to maintain required clearances.
- Cuts to tree branches are to be made outside the branch bark ridge leaving as small a stub as possible.
- Precautions shall be taken to avoid stripping or tearing of bark when cutting large diameter limbs.

7.1.2 Where an easement exists, but the property owner objects to the proposed scope of work, the appropriate Transmission Line Maintenance Specialist shall be notified. The Specialist will consult with ATC Real Estate and/or Legal to resolve this situation and achieve adequate clearances.

7.2 Oak Trimming

7.2.1 All Oak trimming shall be scheduled to accommodate all applicable statutes, regulations and ordinances, including but not limited to Wis. Adm. Code sec. PSC 113.0511 as amended from time to time, established procedures and timelines to prevent the spread of Oak wilt disease.

7.3 Ash Trimming

7.3.1 All Ash trimming shall be conducted in accordance with all applicable statutes, regulations, and ordinances including but not limited to any DATCP Emerald Ash Borer quarantine area requirements.

7.4 Danger/Hazard Trees

7.4.1 Danger/Hazard trees (described below) are trees located outside of the easement width that may fall and come into contact with the electrical facilities. Danger/Hazard trees shall be identified by Contractor and removed where easements allow or otherwise with the property owner's approval..

7.4.2 Danger trees include, but are not necessarily limited to the following conditions: (l) tree defect or wound, (2) sweep towards a line, or (3) a tree position in relation to surrounding trees which subjects it to wind throw. When any of these conditions exist, and where the possibility of tree to conductor contact exists within two years (considering normal growth), the tree shall be removed.

7.5 Crew Caused Outage

7.5.1 If a contract forestry crew causes a line contact, an arc or line outage, the contract forestry crew will discontinue all line clearance activities on the transmission corridor, and immediately:

- Without further endangering personnel, ensure that all personnel are clear of lines and call 911 if emergency response is required.
- Call the ATC system operator and notify them of the event.
- Call the appropriate ATC Transmission Line Maintenance Specialist and wait for further instructions.

7.6 Distribution Underbuild Clearance Requirements

7.6.1 When the transmission line structures have underbuild distribution circuits attached, Contractor shall trim Undesirable Species from the distribution lines as a part of this ATC specification.

7.6.2 Undesirable Species shall be trimmed or removed to provide a minimum fifteen (15)-foot clearance from primary distribution underbuild conductors.

8.0 Transmission Line Right-of-Way Records

8.1 Data Collection and Forms

8.1.1 Contractor shall provide accurate information in the report specified below. Data shall be provided in an electronic format.

8.1.2 All reports shall be forwarded to the appropriate ATC Transmission Line Maintenance Specialist via Email.

8.2 Right-of-Way Progress Report

8.2.1 This report shall provide individual span information for all spans cleared during the preceding work period. Reporting periods shall be no longer than 1 month. It shall be provided with the invoice for the Services, no later than 2-weeks after the right-of-way clearing has been completed, and all information listed below shall be contained in this report.

Heading - Each report sheet shall have the information listed below in the heading.

- Former Utility Name
- Span Number
- Date
- LDC
- District Contractor Name
- Page Number
- Circuit Number
- Forestry Crew Leader

Report Content:

- Type of Access
- Forestry (Y/N)
- Type of Treatment
- Urban/Rural
- Labor Hours
- Type of Herbicide
- Agricultural (Y/IN)
- Equipment Type
- Equipment Hours
- Special Conditions
- Right-of Way Width
- Wetland (Y/N)
- ATC Facility Defect

The report shall summarize each individual forestry crew's work. It shall provide the total number of spans of right-of way cleared, percentage and cost of all spans cleared, and right-of-way categories. The total expenditure for the period as well as the average cost per span shall be calculated.

9.0 Additional Information

9.1 Appendices

9.1.1 Appendix A – Lists of Desireable\Undesireable\Invasive Species by Wire Border Zone

9.1.2 Appendix B – Guidelines for Prescribing Bush Control Treatments

9.2 References

9.2.1 ANSI Z133.1, American National Standard for Arboricultural Operations Safety Requirements

9.2.2 Wisconsin Admin Code PSC 113.0510

9.2.3 FAC-003-1 ,Transmission Vegetation Management Program

9.2.4 GD-0480, Document Control Guide

9.3 This specification shall be reviewed periodically in accordance with ATC Guide GD-0480 to ensure it reflects current practices.

9.4 Revision Information

Version	Author	Date	Section	Description
01	J. McCabe	09-17-07	All	Replaces ATC Operating Instruction Transmission Line ROW Forestry Specification, Rev. 1
02	J. McCabe	08-25-08	All	General cleanup and clarification of specification to reflect current practices and compliance with NERC Reliability Standard FAC-003-1.

Appendix A

Lists of Desirable\Undesirable\Invasive Vegetation Species by Wire\Border Zone

NOTE: These listings are not all inclusive. Check with the ATC Environmental Department for categorization of other species.

Desirable Species that May be Retained in the "Border Zones"

(Species of lower growth form that are compatible with electric rights-of-way and planted so as not to interfere with access)

Scientific Name	**Common Name**
Comptoria peregrina	
Cornus alternifolia	Sweetfern
Cornus amomum	Alternate Leaf Dogwood
Cornus racemosa	Silky Dogwood
Cornus stolonifera	Gray Dogwood
Corylus Americana	Redosier Dogwood
Corylus cornuta	American Hazelnut
Gaylussacia spp.	Beaked Hazelnut
Hammamelis virginiana	Huckleberry
Ilex verticillata	Witchhazel
Lindera benzoin	Common winterberry
Rosa spp.	Spicebush
Rubus spp.	Rose (including wild rose)
	Brambles (including wild
Sambucus Canadensis	raspberry, blackberry, etc.)
Sambucus pubens	Common Elderberry
Spirea spp.	Scarlet Elderberry
Vaccinium spp.	Spirea
Viburnum acerifolium	Blueberry
Viburnum alnifolium	Mapleleaf Viburnum
Viburnum cassinoides	Hobblebush
Viburnum lentago	Witherod
Viburnum recognitum	Nannyberry
Acer spicatum	Arrowood
Amelanchier	Mountain Maple
Carpinus caroliniana	Shadbush
Cornus florida	American Hornbeam
Crataegus spp.	Flowering Dogwood
Juniperus virginiana	Hawthorn
Ostrya virginiana	Red Cedar
Prunus virginiana	Hop Hornbeam
Malus spp.	Choke Cherry
Rhus spp.	Apple
	Sumac

Undesirable Species to be Removed from the "Wire and Border Zones"

Species that may exceed the heights described in this Specification and are therefore incompatible with electric rights-of-way.

Scientific Name	Common Name
Abies balsamea	Balsam Fir
Acer negundo	Boxelder
Acer spp.	Maples
Betula spp.	Birches
Carya spp.	Hickories
Fagus grandifolia	American Beech
Fraxinus spp.	Ash
Juglans cinerea	Butternut
Juglans nigra	Black Walnut
Juniperus virginiana	Eastern Red Cedar
Larix laricina	Tamarack
Picea spp.	Spruces
Pinus spp.	Pines
Popuius spp.	Aspens and Cottonwood
Prunus spp.	Cherries
Quercus spp.	Oaks
Robinia pseudoacacia	Black Locust
Salix spp.	Willows (Tall Growing)
Tilia Americana	Basswood
Tsuga Canadensis	Hemlock
Ulmus spp.	Elm

Tall Growing Invasive Species to be Removed from the Wire Zone and Border Zone.

(Species that, because of their height or growth potential, is incompatible with electric rights-of-way).

Scientific Name	Common Name
Trees:	
Ailanthus altissima	Tree of Heaven
Alnus glutinosa	European (Black) Alder
Elaeagnus angustifolia	Russian Olive
Elaeagnus umbellate	Autumn Olive
Morus alba	White Mulberry
Rhamnus cathartica	Buckthorns: Common
Rhamnus frangula	Buckthorns: Glossy
Sorbus acuparia	European Mountain Ash

Low Growing Invasive Species to be Removed from the Wire Zone and Border Zone.

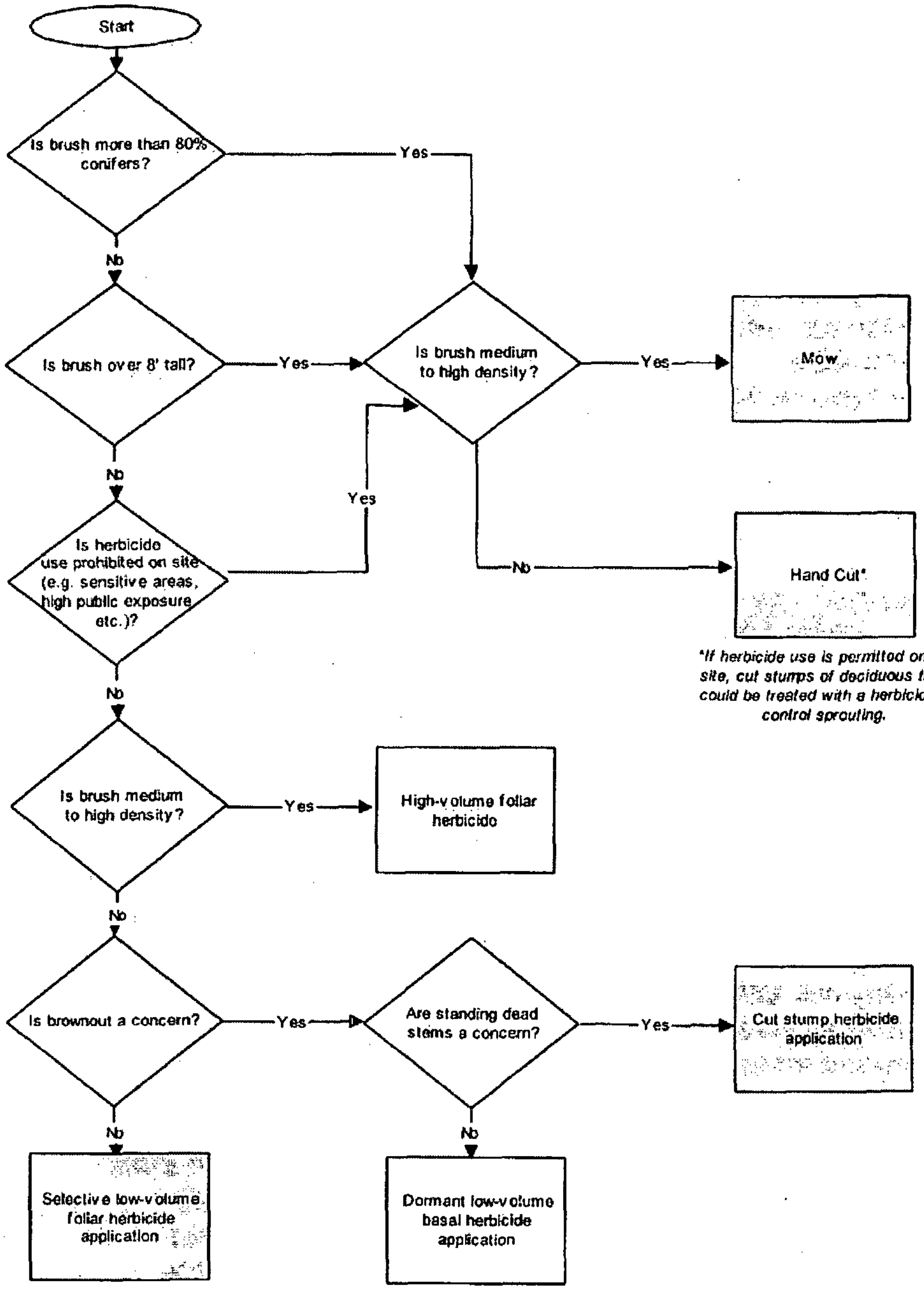
(Species that, because of their growth potential, are incompatible with electric rights-of-way; except when in landscape plantings)

Scientific Name	**Common Name**
Shrubs:	
Berberis thunbergii	Japanese Barberry
Berberis vulgaris	European Barberry
Caragana arborescens	Siberian Pea Shrub
Euonymus alatus	Burning Bush
Ligustrum vulgare	Common Privet
Lonicera maacki	Amur Honeysuckle
Lonicera morrowii	Honeysuckle: Tartarian
Lonicera tatarica	Honeysuckle: Morrow's
Lonicera x bella	Honeysuckle: Bella
Rhodotypos scandens	Black jet-bead
Rosa multiflora	Multiflora Rose
Viburum lantana	Wayfaring Tree
Viburnum opulus	European Highbush Cranberry

Appendix B

Guidelines for Prescribing Bush Control Treatments

This matrix is a general guideline for prescribing an appropriate brush control treatment for individual sites not managed for allowable cr nurseries or orchards. Individual area specifications and characteristics should be evaluated when using this matrix.



**If herbicide use is permitted on the site, cut stumps of deciduous trees could be treated with a herbicide to control sprouting.*

Note: Brush refers to undesirable woody vegetation. This guide is not intended to address appropriate timing of treatments. Multiple treatments may be required within any given span, depending on condition and location of undesirable vegetation (wire zone versus boarder zone).

ENCLOSURE C

AQUATIC ECOLOGY

Documents Included in this Enclosure

1. 1974 Pre-Operation Monitoring Report to Wisconsin Public Services Group, Third Annual Report, 3/29/74 (Note: 1st volume only)
2. 1977 Operational Monitoring Report, Sixth Annual Report, March 1, 1977 (Note: 1st volume only)

KEWAUNEE POWER STATION
DOMINION ENERGY KEWAUNEE, INC.

Industrial **BIO-TEST** *Laboratories, Inc.*
1810 FRONTAGE ROAD
NORTHBROOK, ILLINOIS 60062

XICOLOGY
VIRONMENTAL SCIENCES
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DICAL SCIENCES

AREA CODE 312
TELEPHONE 272-3030

REPORT TO

WISCONSIN PUBLIC SERVICE CORPORATION
GREEN BAY, WISCONSIN

PREOPERATIONAL THERMAL MONITORING PROGRAM OF LAKE MICHIGAN NEAR THE KEWAUNEE NUCLEAR POWER PLANT

JANUARY-DECEMBER 1973
IBT NO. 643-03208

THIRD ANNUAL REPORT

PREPARED AND SUBMITTED
BY
INDUSTRIAL BIO-TEST LABORATORIES, INC.

Report approved by:

G. W. Wadley, Ph. D.
Technical Manager
Environmental Sciences

B. G. Johnson, Ph. D.
Manager
Environmental Sciences

March 29, 1974

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PREFACE

Lake Michigan Thermal Standards were adopted by the Natural Resources Board of the Wisconsin Department of Natural Resources on 8 December 1971 which became effective 1 February 1972. These standards appear in the latest revision of the Wisconsin Administrative Code, Chapter NR 102. Water Quality Standards for Wisconsin Surface Waters (effective 1 October 1973). These standards require that all owners utilizing, maintaining or presently constructing sources of thermal discharges exceeding a daily average of 500 million BTU per hour shall on or before 1 February 1974 complete an investigation and study of the environmental and ecological impact of such discharge in a manner approved by the Department. After a review of the environmental and ecological impact of the discharge, a mixing zone shall be established by the Department beyond which the thermal discharge shall not raise the receiving water temperature by more than 3F. The thermal discharge from the Kewaunee Nuclear Power Plant, in the process of being constructed on 1 February 1972 on the western shore of Lake Michigan by Wisconsin Public Service Corporation, is expected to produce an average of 2 1/2 billion BTU per hour when operational. This makes an environmental and ecological impact study of the thermal discharge mandatory. Specific guidelines for designing such environmental studies have been established by the Wisconsin Department of Natural Resources' Division of Environmental Protection. These guidelines cover the following general categories:

1. Predictive model of the thermal plume;
2. Environmental considerations;
3. Special studies; and
4. Other factors to consider.

This report covers the second year of environmental and ecological studies in response to the Wisconsin Department of Natural Resources guidelines.

In addition to being responsive to the Wisconsin Department of Natural Resources' guidelines, the 1973 preoperational studies were also responsive to the Technical Specifications for the Kewaunee Nuclear Power Plant, Appendix B-Environmental Technical Specifications, as approved by the U.S. Atomic Energy Commission. Although the Technical Specifications are applicable to operating conditions at the KNPP, the 1973 studies, by following the Technical Specifications, provide the necessary continuity in the environmental programs from preoperational to operational periods.

ACKNOWLEDGEMENTS

The Environmental Sciences Division of Industrial BIO-TEST Laboratories, Inc. acknowledges and appreciates the technical assistance contributed by the following members of its consulting staff:

Dr. W. Hoagman Fisheries Biology	Virginia Institute of Marine Science
Dr. D. A. McCaughran Biostatistics	University of Washington
Dr. G. W. Prescott Phycology	University of Montana
Dr. R. G. Wetzel Algal Physiology	Michigan State University

The overall coordination of the study program was the responsibility of Dr. B. G. Johnson, Manager, Environmental Sciences Division. The direction of the environmental and ecological studies was the responsibility of Mr. J. H. Rains, Associate Biologist, Aquatic Ecology Section. The direction of the thermal plume model study was the responsibility of Mr. F. T. Lovorn, Oceanographer, Physical Sciences Section.

The following BIO-TEST personnel provided technical and supervisory assistance to the authors of specific chapters in this report:

Mr. J. C. O'Neill	Physical Hydrology-Oceanography
Dr. J. E. Hawley	Water Chemistry
Mr. L. D. Everhart	Aquatic Ecology
Dr. R. G. Otto	Environmental Physiology
Mr. B. I. Muench	Fisheries

Appreciation is expressed to P. Parshall and N. Gara for their cartography work, to R. Buckner for editorial assistance, and to J. Pasternak for manuscript preparation.

The assistance provided by Mr. Thomas P. Meinz of Wisconsin Public Service Corporation during the course of these studies has also been greatly appreciated.

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GENERAL INTRODUCTION AND SUMMARY

B. G. Johnson and J. H. Rains

PREOPERATIONAL THERMAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR KEWAUNEE NUCLEAR POWER PLANT

THIRD ANNUAL REPORT
January-December 1973

GENERAL INTRODUCTION AND SUMMARY

B. G. Johnson and Joseph H. Rains

I. Introduction

This report covers a third year of preoperational thermal monitoring conducted during 1973, continuing the thermal impact studies to document the physical, chemical and biological conditions of Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant near Kewaunee, Wisconsin. In addition, it constitutes the second year of studies required by the Wisconsin Department of Natural Resources under the adopted Lake Michigan Thermal Standards for the State of Wisconsin.

The Kewaunee Nuclear Power Plant is located on the west shore of Lake Michigan, approximately 8 miles south of Kewaunee, 27 miles southeast of Green Bay, and 90 miles north of Milwaukee. The facility will employ a single pressurized water reactor (PWR) nuclear generating unit and will produce a net output of 540 megawatts electric (MWe). The unit is scheduled to begin operation in early 1974.

Lake Michigan water will be circulated in the once-through cooling system which has a shoreline discharge. The cooling water intake structure is located approximately 1,600 feet offshore at a depth of 16 feet. Condenser cooling water will be drawn from Lake Michigan at a rate of 287,000 gallons per minute (gpm) during winter and 413,000 gpm during summer. The maximum rise in cooling water temperature is expected to be 28F (15.5C) and 20F (11.1C) above intake temperature for winter and summer, respectively.

Cooling water will be discharged into an outlet basin at the shoreline through a pipe located just below the lake surface.

The 1973 preoperational monitoring studies were based on a total of 36 sampling locations in the vicinity of the Kewaunee Nuclear Power Plant (Figures 1, 2 and 3). Lake sampling was conducted along five east-west transects. A central transect was situated directly offshore from the mouth of the discharge. There were two transects on each side of and running parallel to the central transect: one approximately one-half statute mile and the other approximately two statute miles from the central transect. The sampling locations were positioned along each transect on the basis of the distance from the discharge and the water depth. Sampling points were found using shipboard radar and electronic depth sounding instrumentation.

The frequency of sampling for each category is presented in Table 1. Temperature and near-shore currents were monitored on a continuous basis, April through December. Aerial photographs of the shoreline in the vicinity of the Plant were taken quarterly to determine the extent of beach erosion or deposition. Entrainment sampling was conducted on a monthly basis, March through December. One supplemental entrainment sampling during chlorination equipment testing was conducted during the year. Water quality, bacteriology, temperature and dissolved oxygen (D. O.) profiles, phytoplankton, zooplankton, and fish (gill nets and shoreline seining) were sampled monthly, April through November. Benthos, periphyton and fish eggs and larvae were sampled during April, May, July, September, and November. General descriptive field data

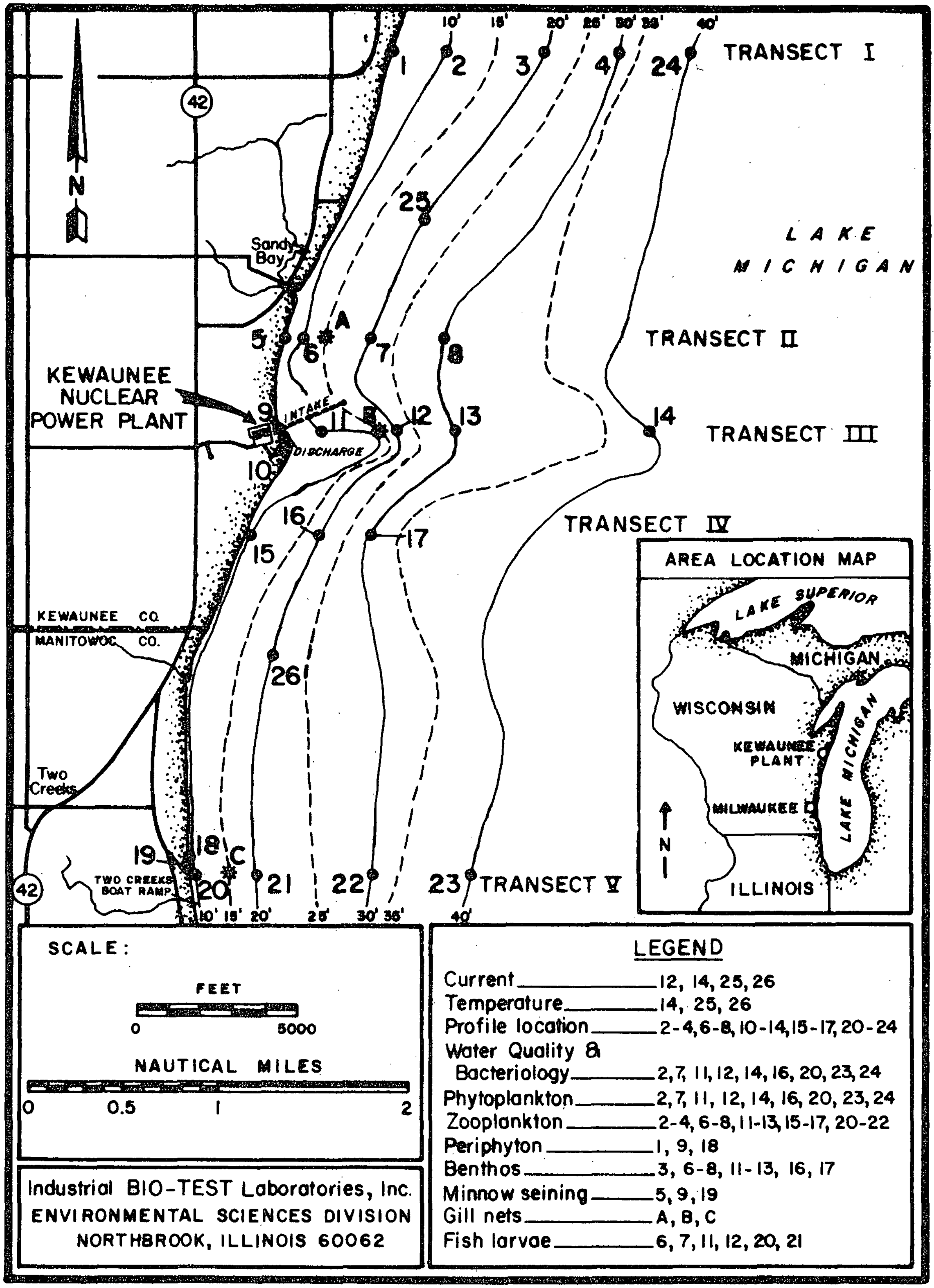

Figure 1. Sampling locations near the Kewaunee Nuclear Power Plant during 1973.

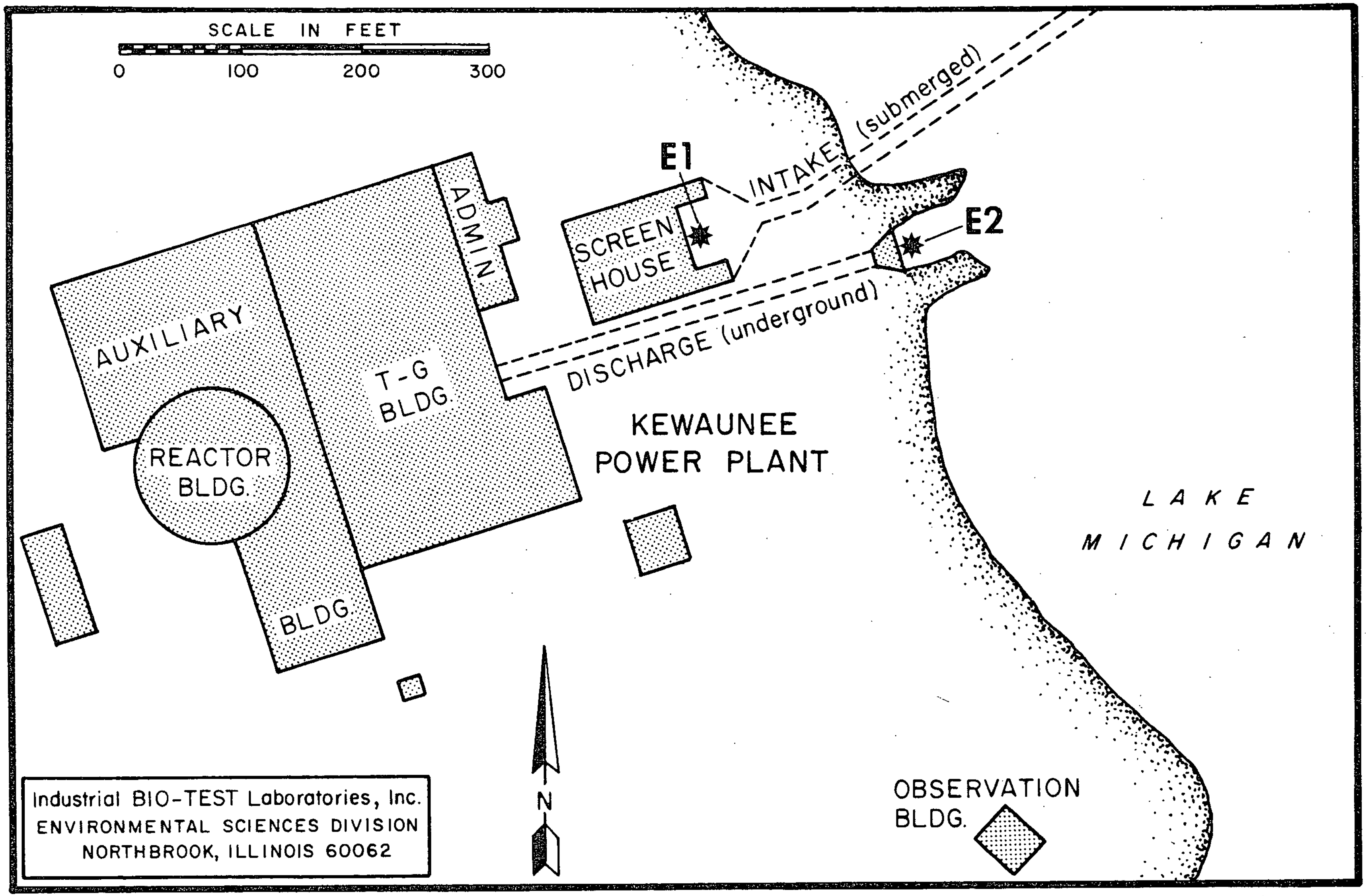

Figure 2. Phytoplankton and zooplankton entrainment sampling locations near the Kewaunee Nuclear Power Plant during 1973.

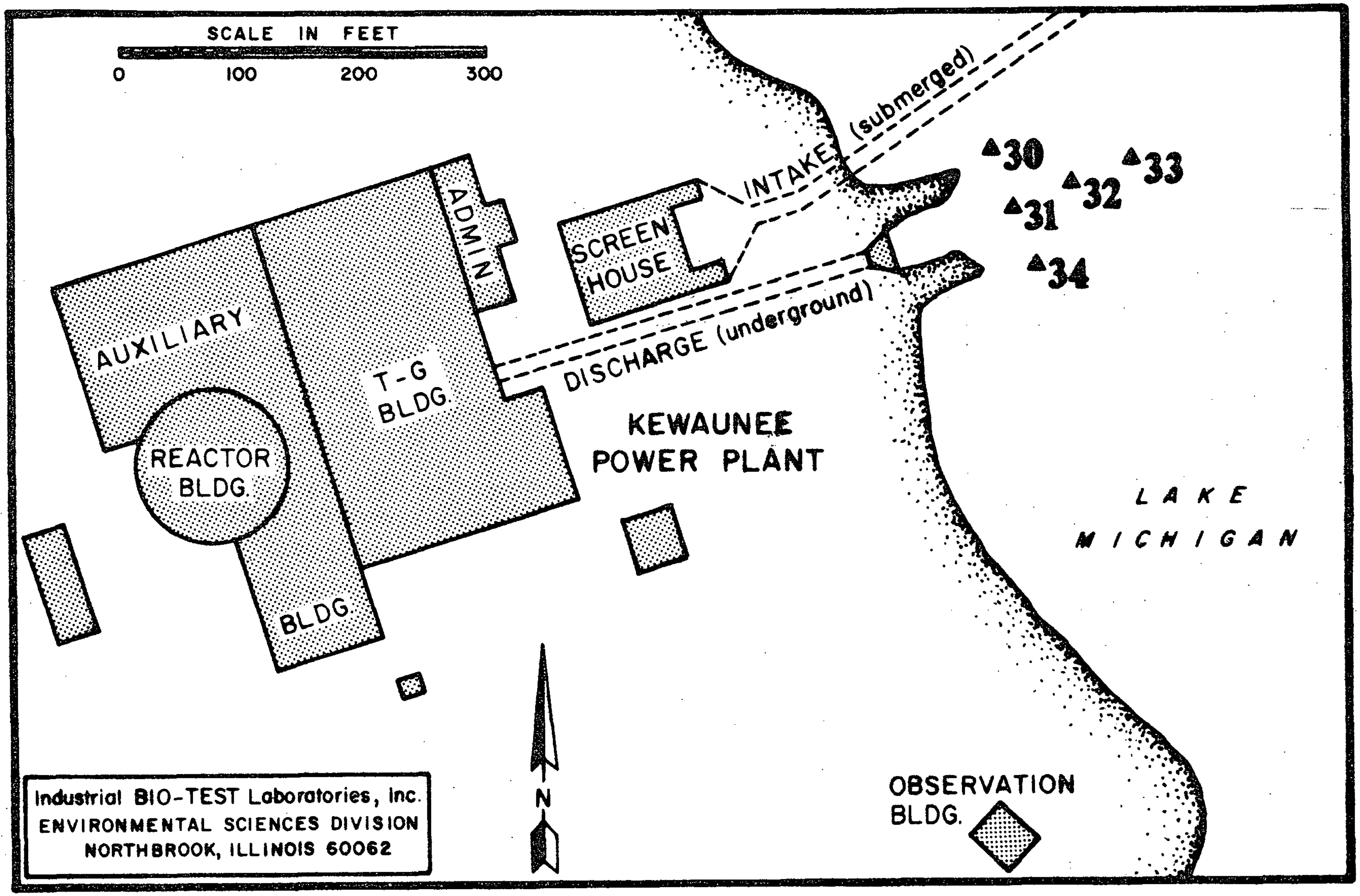

Figure 3. Sediment sampling locations near the Kewaunee Nuclear Power Plant during 1973.

Table 1. Field sampling schedule for the preoperational aquatic thermal monitoring program in the vicinity of the Kewaunee Nuclear Power Plant, 1973.

Category	Sampling Period									
	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Currents and Temperature[a]	-	X	X	X	X	X	X	X	X	X
Chemistry										
Water Quality	-	X	X	X	X	X	X	X	X	-
Bacteriology	-	X	X	X	X	X	X	X	X	-
Profiles (DO and Temperature)	-	X	X	X	X	X	X	X	X	-
Biology										
Phytoplankton	-	X	X	X	X	X	X	X	X	-
Zooplankton	-	X	X	X	X	X	X	X	X	-
Periphyton	-	-	X	-	X	-	X	-	X	-
Benthos	-	X	X	-	X	-	X	-	X	-
Entrainment										
Phytoplankton Physiology	X	X	X	X	X	X	X	X	X	X
Zooplankton Physiology	X	X	X	X	X	X	X	X	X	X
Fisheries										
Minnow Seining	-	X	X	X	X	X	X	X	X	-
Gill Netting	-	X	X	X	X	X	X	X	X	-
Fish Eggs and Larvae	-	X	X	-	X	-	X	-	X	-
Sediment Characterization	-	-	X	-	-	-	-	X	-	-
Shoreline Erosion	X	-	-	X	-	-	X	-	-	X
Bottom Topography	-	-	-	X	-	-	-	X	-	-

---

[a] Included continuous measurements.

collected at each sampling location included wind direction and speed, percent cloud cover, water color, secchi disc reading, and time of day.

The 1973 studies also included the development of a numerical predictive thermal plume model for the Kewaunee Nuclear Power Plant plume.

The results of all 1973 studies are reported under technical titles in individual chapters of this report. The specific objectives of each individual study are covered in detail in the respective chapter, together with a presentation of results and conclusions. All numerical data collected or developed are presented in the Appendix, Volumes I and II.

II. Summary

The data collected as part of these 1973 studies, together with those from the two previous programs in 1971 and 1972, provide a detailed description of preoperational conditions in the vicinity of the Kewaunee Nuclear Power Plant. This information will be used as the data base to which operational data can be compared in an effort to determine the effects of the thermal discharge on the aquatic environment. The development of the numerical predictive thermal plume model will assist in defining the physical aspects associated with plant operation that relate to the potential impact of plant operation on the Lake Michigan environment.

The following points provide a compendious summary of studies conducted to date:

1. The preoperational conditions in the aquatic environment in the vicinity of the Kewaunee Nuclear Power Plant have been described;
2. The preoperational baseline data to which future operational data may be compared have been developed; and
3. No unusually sensitive environmental or ecological area has been identified that would warrent modifying present plans of the Wisconsin Public Service Corporation to proceed with operating the Kewaunee Nuclear Power Plant.

The summary and conclusions from each of the 1973 studies reported under individual technical titles in chapters of this report follow:

Chapter 1. Nearshore Currents and Temperatures

1. The data collected describe the spatial and temporal near shore circulations and temperature distribution in the vicinity of KNPP for the measurement period and provide temperature estimates for the non-measurement period (November-April).

2. The data collected was sufficiently representative to provide useful input into the predictive aspects of the KNPP thermal plume model.

3. The water mass movement in the area of KNPP is spatially homogeneous in speed, but the direction of flow is dependent upon the bottom topography and the prevailing local winds.

4. Northward flowing currents generally occur simultaneously at all locations whereas southward flowing currents do not generally occur simultaneously at all locations.

5. The promontory in the region of the condenser cooling water intake plays a major role in the general water circulation in the vicinity of the KNPP.

6. The net displacement of water past the KNPP was generally shore-parallel and to the north at an approximate mean velocity of 0.08 ft/sec.

7. Periods of greatest temperature range occurred during August. This range was found to be as great as 14C.

8. Temperature minimums recorded at the South Mooring were always warmer than those measured at other locations.

9. A maximum temperature of 20.6C was recorded during August

in the area of the intake, and maximum temperatures of 20.2 and 21.0C were recorded during August at the Offshore Deep and South Mooring locations respectively.

10. Monthly mean temperatures at all locations differed by 0.5C or less.

11. Rapid temperature changes due to upwelling and downwelling in the vicinity of the condenser cooling water intake were found to be as great as 11C in a 24 hr period at an approximate depth of 8 ft.

12. Fluctuations in the temperature records which were near the inertial period occurred frequently.

13. Sufficient wind data recorded simultaneously with the current data were unavailable. This limited the establishment of definitive and predictive relationships of water circulation based upon knowledge of the wind characteristics.

14. There is sufficient evidence to suggest a more thorough investigation of the circulation and temperature structure in the vicinity of the promontory might be warranted. Such a study would attempt to determine the presence of gyres or other phenomena which might occur and act as a heat sink by trapping a portion of the thermal discharge.

Chapter 2. Water Chemistry and Bacteriology

1. The values of those water quality parameters measured in Lake Michigan near the Kewaunee Nuclear Power Plant were within the accepted limits of Wisconsin State Standards with the exception of several iron and

turbidity values. Iron and turbidity values were high when meteorological conditions resulted in greater nearshore bottom scouring due to increased wave activity.

2. The outflow from the Kewaunee River had no apparent effect on water quality in Lake Michigan near KNPP.

3. The existence of a thermocline in the study area was influenced by weather conditions, and a thermocline was present during relatively quiescent periods in June, August, September and October. The distribution of D.O., soluble silica, B.O.D., and pH in the water column was influenced by the presence of the thermocline.

4. Nutrient parameters such as soluble silica, nitrate and nitrite, and total organic carbon were not directly related to phytoplankton abundance. An inverse relationship between nitrite and nitrate values was apparent. Silica values were stratified during the months when a thermocline was present and levels were higher for bottom samples than for top samples.

5. Weather-dependent parameters included total phosphorus, manganese, iron, nonfiltrable residue, turbidity, total organic nitrogen, calcium, potassium, and magnesium. Higher levels were apparent during turbulent periods and are related to the abundance of these constituents in the bottom sediments.

6. Bacterial values were higher in samples collected south of KNPP than north of it indicating that the southern area is receiving more surface run-off. Standard plate counts and coliform bacteria were related to weather conditions which caused turbid waters.

7. Several weather-dependent parameters including iron, total phosphorus and turbidity were higher in 1972 than during the 1973 study, indicating that lake conditions may have been calmer during the 1973 samplings. Other data from the area are quite similar to data from the previous preoperational studies conducted during 1971 and 1972, and to other data collected from the area.

8. The results of the special chlorination study showed that total residual chlorine levels in the circulating water system could be effectively controlled so that levels do not exceed 0.1 mg/l at the point of discharge to Lake Michigan.

Chapter 3. Phytoplankton

1. Seven major algal divisions were collected near the Kewaunee Nuclear Power Plant. The four major divisions, in decreasing order of abundance, included Bacillariophyta (diatoms), Cyanophyta (blue green algae), Chlorophyta (green algae) and Chrysophyta (golden brown algae).

2. Phytoplankton species composition changed very little from 1971 to 1973, with diatoms dominating all three years. Dominant diatom species during all three years included *Fragilaria crotonensis*, *Fragilaria pinnata*, *Cyclotella stelligera*, *Tabellaria flocculosa*, *Asterionella formosa* and *Stephanodiscus* sp.

3. Blue green algae were second in order of abundance. They were most abundant and were the dominant group in August. *Coelosphaerium naegelianum* was the most common blue green species collected in 1971, 1972 and 1973.

4. Green algae were the second most diverse algal division although they never composed more than 9% of the total phytoplankton at any sampling location. No green algal species were dominant.

5. Golden brown algae were less abundant in 1973 than in 1972, but the dominant species were the same. These included Dinobryon cylindricum, D. divergens, and D. sociale. Abundance of golden brown algae steadily declined from April through October and then increased slightly in November.

6. Phytoplankton populations at the inshore locations were generally significantly greater than at the offshore locations. This was especially true for diatoms and golden brown algae.

7. Nutrient levels were sufficient to support algal growth but not nuisance blooms. Definite relationships between nutrient levels and phytoplankton abundance were not discernible.

Chapter 4. Zooplankton

1. A total of 37 species of planktonic Crustacea were collected. Fifteen of these species were not reported in 1972. Three species that were reported in 1972 were not observed in 1973.

2. Total zooplankton populations were highest in the months of July, August, and September, and in November.

3. The most abundant taxa observed were immature Copepoda, Bosmina longirostris, total Rotifera, Daphnia retrocurva, Cyclops bicuspidatus thomasi, and Tropocyclops prasinus mexicanus.

4. Calanoid copepodites were more concentrated at offshore locations than inshore during the non-winter months.

5. Significant differences among locations did not yield discernable patterns of spatial distributions in the Kewaunee area.

6. There was a general depression in zooplankton populations during the October sampling date.

7. Fluctuations between the percentages of Copepoda and Cladocera in the total microcrustacea were more subdued in 1972 than in 1973.

8. In May of 1972 the adult copepods, particularly Diaptomus spp., were much more numerous than in May of 1973.

9. Tropocyclops prasinus mexicanus in 1973 was much more numerous and occupied a larger percentage of the copepod adults than it did in 1972.

Chapter 5. Phytoplankton Entrainment

1. Reductions in carbon fixation rate (a measurement of phytoplankton photosynthetic activity) ranged from 1 to 34% at the discharge when compared with the intake during normal sampling conditions, with an annual mean reduction of 13.5%. Twenty-seven of the 40 comparisons made showed that the reduction was significant ($P \leq 0.05$).

2. Reductions in chlorophyll a concentrations (a relative index of phytoplankton biomass) ranged from 0 to 19% at the discharge when compared with the intake during normal sampling conditions, with an annual mean reduction of 9%. Eleven of the 40 comparisons made showed that the reduction was significant.

3. Reductions in phytoplankton abundance (density) ranged from 0 to 27% at the discharge when compared with the intake. The mean annual reduction was 11%.

4. Diatoms (Bacillariophyta) composed the greatest portion of the total phytoplankton passing through the Plant during the period from March through December. The pennate diatoms, Fragilaria crotonensis, Tabellaria flocculosa, and Synedra filiformis were frequently reduced in number following entrainment.

5. Significant reductions ($P \leq 0.05$) in carbon fixation rate and chlorophyll a concentration were observed at the discharge as compared with the intake during special chlorination testing when a total chlorine level of 0.1 mg/l was measured in the discharge.

6. Recovery of phytoplankton viability, as determined by carbon fixation rates and chlorophyll a concentrations, was not detected during the 72-hr period after sample collection during the chlorination study.

Chapter 6. Zooplankton Entrainment.

1. Total zooplankton abundance was greatest from August through December.

2. Population densities for both Copepoda and Cladocera tended to peak during the same seasonal periods.

3. Immotilities for total zooplankton were highly significant ($P \leq 0.01$) for every month except September and October.

4. When small organisms such as immature copepods and

Bosmina longirostris comprised a high percentage of the entire population, the percent immotility from condenser passage was generally low and reflected few, if any, effects from mechanical damage.

5. Binomial regression analyses showed that immotility of entrained zooplankton was a linear function of size.

6. There was a 45% average recovery of immotile zooplankton 4 hr after entrainment in seven of the ten months of testing, resulting in a 3.9% average mortality.

7. Zooplankton viability showed an average reduction of 5.1% for the year due to mechanical entrainment effects.

8. Chlorination of condenser cooling water in June resulted in increased immotility and mortality of zooplankton present.

Chapter 7. Periphyton

1. One hundred-fourteen periphytic algal taxa were collected from natural substrates, representing the Bacillariophyta (diatoms), Chlorophyta (green algae) and Cyanophyta (blue-green algae) divisions.

2. Total periphytic abundance and biovolume varied between locations and showed a general increase from May to November. Differences between locations could have been due in part to the different types of substrates sampled at each location.

3. Bacillariophyta (diatoms) were present throughout the study and were represented by 91 taxa belonging to 13 genera. Diatoms represented the majority of the periphytic community in May but decreased in abundance in

subsequent months. Gomphonema olivaceum, Fragilaria intermedia, Fragilaria construens, Fragilaria vaucheriae and Cymbella prostrata were the dominant diatom species collected during the study.

4. Chlorophyta (green algae) comprised the major portion of the periphytic community after May and was represented by five taxa belonging to three genera. Green algae increased in abundance and biovolume throughout the study period. Ulothrix zonata and Cladophora glomerata represented the majority of the periphytic growth of the two species in the study area. Ulothrix zonata was dominant in May and July, while C. glomerata was dominant in September and November.

5. Cyanophyta (blue-green algae) represented a small portion of the periphytic community and was comprised of eight taxa belonging to five genera. Dominant blue-green algal species included Phormidium tenue, Calothrix parientana and Oscillatoria amoena.

6. There were no changes in periphytic species composition beyond normal species variation between the 1973 study and the 1971 and 1972 studies. Changes in abundant diatom taxa were attributed to the different analytical methods used to determine relative abundance.

7. Concentrations of the major nutrients, nitrate and total phosphorus, were below hypothetical critical levels that could result in excessive growths of attached algae.

Chapter 8. Benthos

1. Abundance of benthos increased with increasing depth. Total

populations were largest in September when 12992 organisms/m^2 were recorded, and smallest in April when 1340 organisms/m^2 were recorded.

2. There were few significant ($P \leq 0.05$) differences among benthic populations at locations on the same depth contour.

3. Oligochaetes represented 44% of the benthic community. Naididae accounted for 46% of the Oligochaeta and was comprised almost entirely of Vejdovskyella intermedia. Tubificidae represented 48% of the oligochaetes and Limnodrilus hoffmeisteri and Potamothrix moldaviensis were the most numerous tubificids.

4. Chironomidae represented 19% of the benthos and consisted primarily of Orthocladiinae (43%) and Chironominae (40%).

5. Gammarus pseudolimnaeus was the most abundant amphipod collected in the vicinity of Kewaunee Nuclear Power Plant.

6. Benthos averaged 4653 organisms/m^2 in 1972 and 19752/m^2 in 1973. The increased abundance may have been due to changes in sampling methods which included sampling a smaller area which improved sampling efficiency or increased the proporation of recruited organisms.

7. Thirty-eight taxa collected in 1973 were not collected in 1972. This was probably due to the sampling of a greater number of habitat types in 1973.

Chapter 9. Fish Population and Life History

1. Water temperatures recorded on a given sampling date were similar among the three sampling locations. The highest temperatures

recorded at gill net locations occurred in July (16.1C) and the lowest were recorded in April (2.3C). The highest temperatures at minnow seine locations occurred in August (17.5C) and the lowest were recorded in April (2.1C).

2. Monthly sampling in Lake Michigan with gill nets and minnow seines resulted in the collection of 24 different species of fish in 1973.

3. The total catch for the year was 5427 fish, of which alewife, yellow perch, rainbow smelt, lake trout, lake chub, slimy sculpin, white and longnose suckers and longnose dace were most abundant.

4. The addition of the 1 1/2 inch mesh gill net in 1973 resulted in the collection of younger individuals of larger species (yellow perch, coho and chinook salmon) and greater numbers of smaller species (alewife, rainbow smelt, lake chub).

5. Collections at the sampling locations to the north of KNPP (Locations A/5) produced greater numbers of fish than collections at the other sampling locations. A total of 2198 (40%) fish were collected from this area compared to 1615 (30%) fish from the locations directly offshore of the Plant (Locations B/9), and 1614 (30%) fish from the area to the south of the Plant (Location C/19).

6. Species which may have attempted spawning within the study area were alewife, yellow perch, rainbow smelt, lake trout, lake chub, slimy sculpin and longnose dace. Species believed to have spawned successfully within the study area were alewife, rainbow smelt, lake chub, slimy sculpin, and longnose dace.

7. Total catches over the three year period varied considerably in terms of numbers, seasonal abundance and distribution. More fish were

taken in 1971 than in 1972 or 1973, and more fish were taken in 1973 than in 1972. Individual species varied substantially in their seasonal abundance as well as in their distribution within the study area.

Chapter 10. Bottom Topography

1. In the vicinity of the Kewaunee Nuclear Power Plant, depth contours closely paralleled the outline of the shore.

2. The bottom topography is extremely irregular offshore from the Plant between the 25- and 40-ft depths.

3. Irregular bottom topography, particularly between 25 and 40 ft, made it difficult to locate depth contours exactly.

4. A detailed bathymetric map was prepared for the area in the immediate vicinity of the KNPP intake and discharge.

Chapter 11. Sediment Characterization

1. Fine sand composed an average of 90% of all the sediments collected from Lake Michigan in the immediate vicinity of the Kewaunee discharge for the two sampling periods.

2. Clay, silt, medium to coarse sand, and gravel collectively constituted the remaining 10% of the sediments.

3. On 17 October the sediments at the location directly offshore from the mouth of the discharge consisted of only 58% fine sand and 40% medium to coarse sand and gravel. The cause for this change in composition could not be determined.

Chapter 12. Shoreline Erosion

1. The shoreline in the vicinity of the KNPP is being subjected to severe erosion.

2. The shoreline to the north and south of the KNPP site is generally characterized by a narrow beach backed by steep, unstablized soil banks ranging from 10 to 60 feet in height.

3. The shoreline at the KNPP is generally characterized by a narrow beach and gradual rise in elevation back away from the shore, with the shoreline in the immediate vicinity stablized by rip-rap.

4. Considerable differences in local rates of erosion were apparent within the stretch of shoreline where observations were made during this study.

5. The seasonal period of greatest change in shoreline configuration in 1973 was between March and June.

Chapter 13. Thermal Plume Model

1. The significant predictions of the model include:

   a. The bottom slope at the KNPP site of 1/100 will result in a depth limited plume.

   b. The influence of the Point Beach plume on the KNPP plume will be to decrease slightly the areas within isotherms of excess temperature, but to increase the areas within water temperature isotherms.

   c. Seasonal temperature variations will influence the surface area of the thermal plume with an increase in size from spring to summer and a decrease from summer to fall. The size may increase again from fall to early winter, decreasing again in late winter during minimum lake temperatures.

d. Summer thermal stratification will be a significant factor in reducing the surface area of the thermal plume.

e. Ambient currents will be a significant factor in increasing the surface area of the thermal plume.

f. A sinking thermal plume will occur during the winter. The surface area will decrease from early to late winter. The area of the bottom affected by excess temperatures will increase from early to late winter.

g. A reduction in Plant power will reduce the surface area of the thermal plume.

h. Recirculation will probably occur under conditions of zero or low ambient current.

2. The predicted areas within isotherms are probably optimistic within a distance of 30 discharge widths (1200 ft) from the discharge structure and conservative thereafter.

3. If an eddy is generated by a northward current flowing past the submerged promontory, the ambient temperature will probably be locally increased due to reduced exchange with ambient water. However, the extent to which the KNPP thermal plume will be affected by this eddy has not been successfully modeled.

4. A field program of thermal plume measurements in the vicinity of the KNPP site will be necessary to verify the predictions of the model.

Such a program should at least define the surface area, critical depth, velocity decay, and trajectory of the plume along with the environmental and Plant operating conditions. In addition, an estimate of the relative contribution of dilution and surface cooling to reducing the plume size should be obtained. A field program to study a sinking thermal plume should also be conducted.

Chapter 1

NEARSHORE CURRENTS AND TEMPERATURES

Richard G. Johnson

PREOPERATIONAL THERMAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR KEWAUNEE NUCLEAR POWER PLANT

THIRD ANNUAL REPORT
January-December 1973

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Chapter 1

NEAR SHORE CURRENTS AND TEMPERATURES

Richard G. Johnson

I. Introduction

This field study was conducted during 1973 and represents the third year of the continuous thermal impact investigation to document the preoperational near shore current and temperature conditions of Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant (KNPP). The study of near shore currents and temperatures was expanded considerably in 1973. The specific objectives of the study were:

1. to measure the lake currents in the vicinity of KNPP from April to December using Eulerian techniques (moored current meters) on a time-continuous basis at four locations and Lagrangian techniques (current drogues) on a periodic basis;

2. to describe the spacial and temporal near shore circulation in the vicinity of KNPP based upon the current measurements made;

3. to measure the lake temperature from April to December using time-continuous temperature recorders and detailed monthly temperature profiling techniques;

4. to describe the spacial and temporal near shore temperature structure in the vicinity of KNPP based upon the temperature measurements made; and

5. to collect sufficient representative temperature and current data for use in the predictive aspects of the KNPP numerical thermal plume model.

II. Field and Analytical Procedures

A. Current Measurements

1. Time-Continuous Current Meter Measurements

Current meter measurements were recorded as thirty-minute averages continuously from 11 April to 12 December, 1973, at each of four mooring locations (Figure 1.1). A current meter was located at a depth of approximately 7 ft at each location, using the mooring system shown in Figure 1.2. At the offshore location a second current meter was located at a depth of 26 ft. Three of the five current meters were either lost or stolen during the study; however, one of these was recovered. The meter at the Offshore Surface Mooring was lost in June, but replaced the same month with the unit from the Offshore Deep Mooring. The Offshore Surface Mooring meter was again lost in August, but was found on the bottom and replaced in early September. This unit was again lost in late September and since it could not be found, it was not replaced. These losses resulted in a partial loss of current meter data.

The instruments were serviced twice monthly through May and once a month thereafter. Servicing involved replacement of batteries, film and dessicant bags, and adjustment of the instrument trim.

The current meter (ENDECO Type 105) is an axial flow, ducted impeller instrument specifically designed for use in the near shore zone (Figure 1.3). Analog values of impeller rotation and magnetic bearing of the instrument comprise the data which were recorded on 16 mm film. Each instrument was calibrated prior to installation in a closely controlled flume

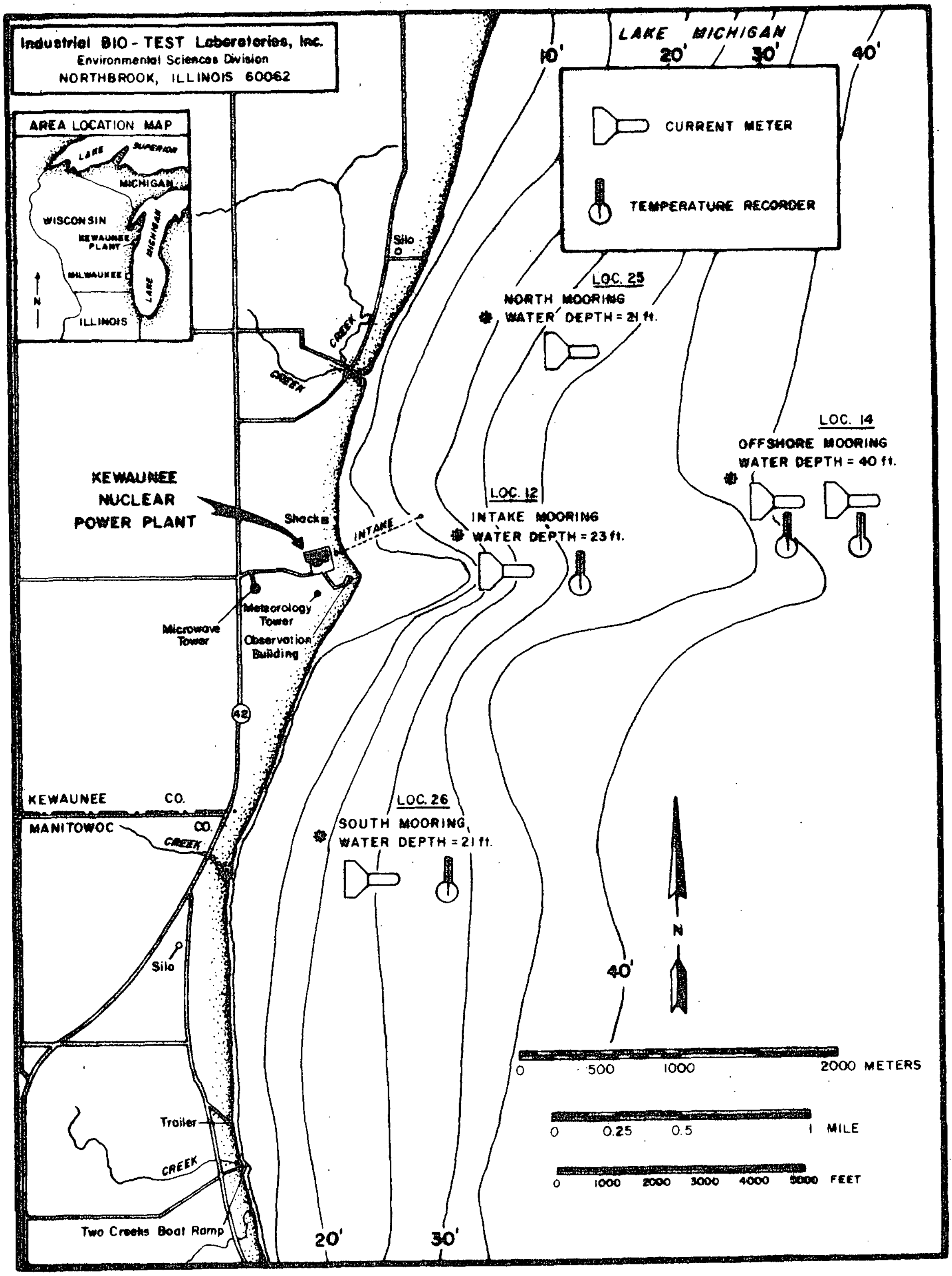


Figure 1.1 Current meter mooring locations in Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant during 1973.

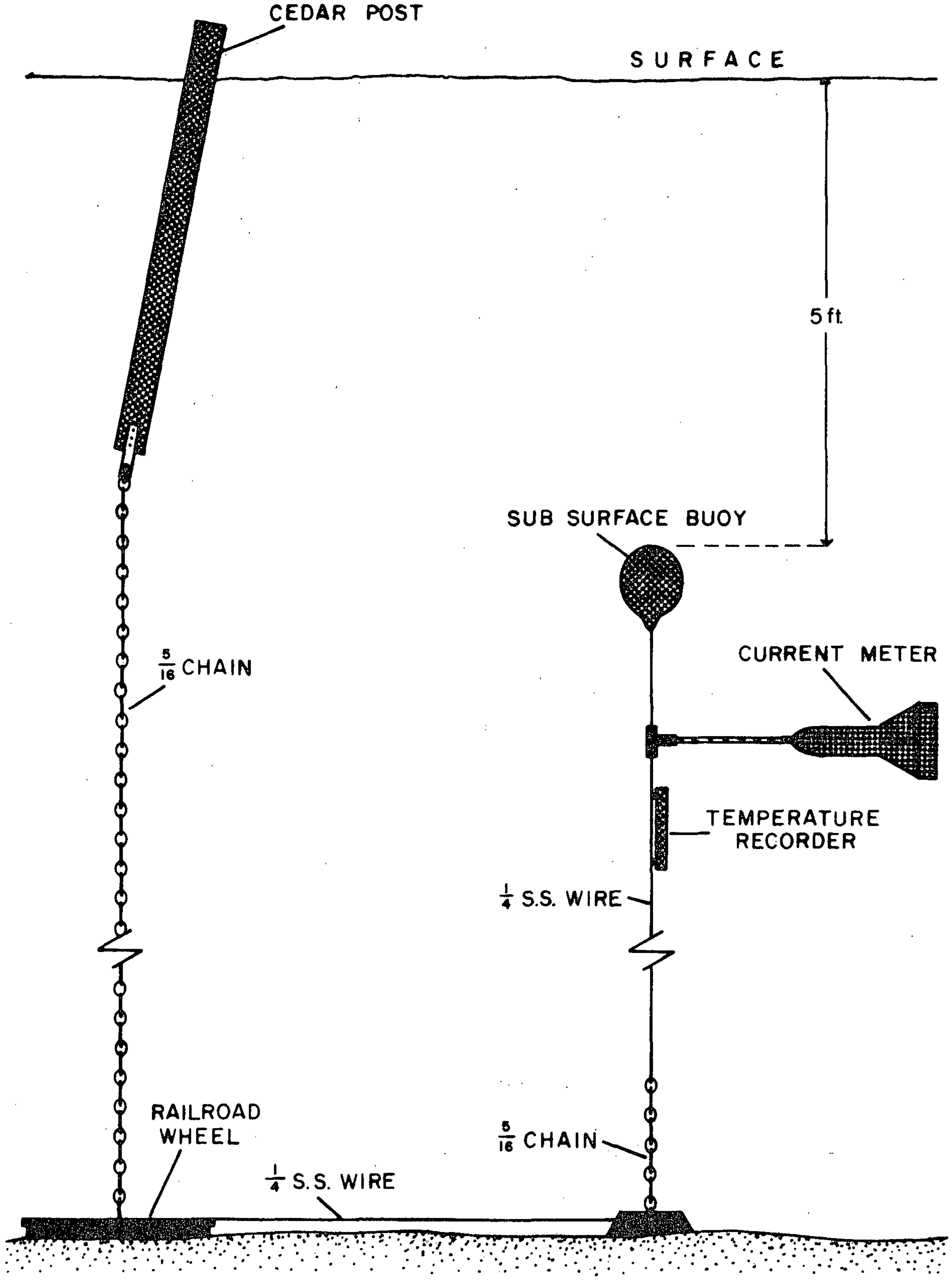
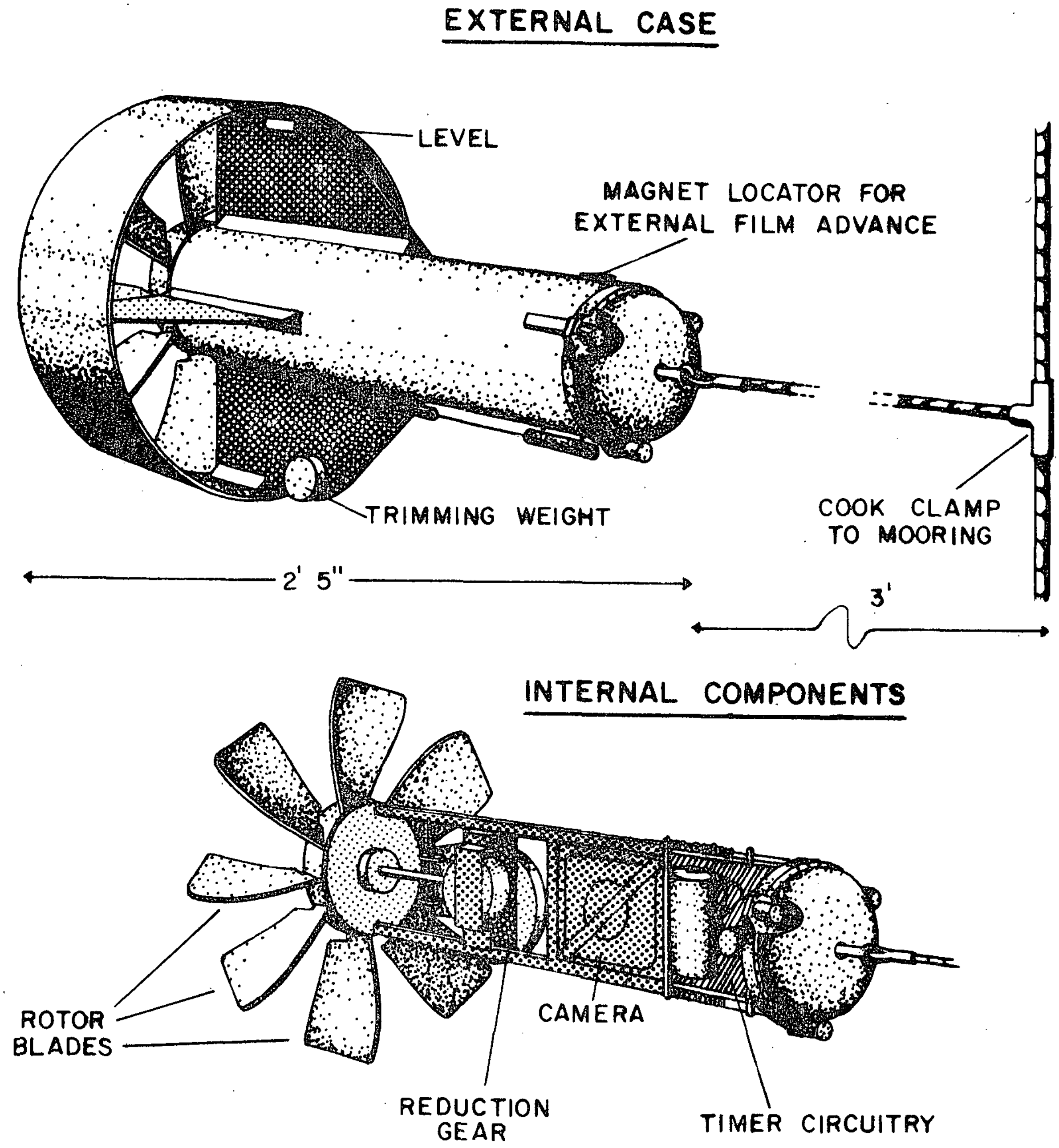


Figure 1.2 Current meter and temperature recorder mooring as used in Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant during 1973.



EXTERNAL CASE

INTERNAL COMPONENTS

Figure 1.3 Recording current meter (ENDECO Type 105) used for time-continuous current recording in Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant during 1973.

to determine threshold speed and accuracy of measurement. The calibrations were conducted for BIO-TEST under the close supervision of HYDROCON personnel at the Chesapeake Bay Institute of The Johns Hopkins University. Threshold speed of each instrument was found to be less than 0.084 ft/sec and accuracy of speed measurement was within ±0.012 ft/sec of true speed. Current direction accuracy was ±5 degrees at a speed of 0.084 ft/sec (threshold), ±3.6 degrees above 0.084 ft/sec, and is resolvable to ±1.0 degrees.

Time series data of hourly vector averages of current speed and direction were used to construct plots of speed and direction versus time, Progressive Vector Diagrams (PROVECS), and Joint Frequency Tables of lake current speed and direction. Current meter data were compared with available wind data to assess the extent of correlation between wind and water movement.

2. Current Drogue Measurements

Drogue measurements were attempted monthly April through December to estimate spacial variations in current speed and direction in the vicinity of the KNPP site. Drogue studies were not conducted during August and November due to high winds and poor visibility.

The drogues consisted of a weighted cross vane suspended from a styrofoam surface float (Figure 1.4). The vanes were suspended at depths of 0, 6, 12 or 18 ft and allowed to drift for several hours. The location of the drogues was periodically determined by two transit bearings from shore. Window shade (Sail) drogues (Figure 1.4) were used in addition to cross vane

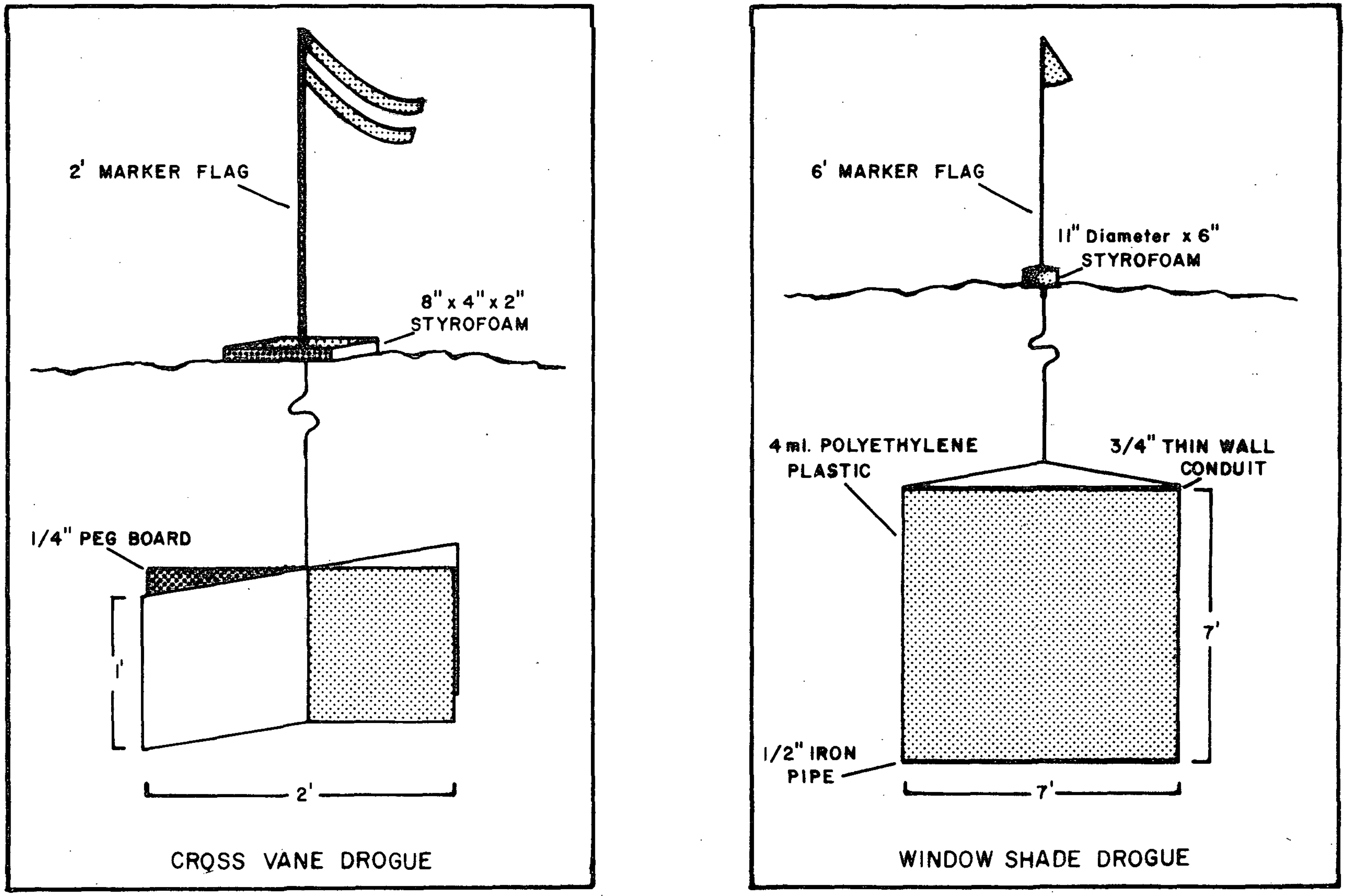


Figure P.4 Cross vane and window shade current drogues used in Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant during 1973.

drogues in December to compare their performances. Plots of drogue movement were constructed for each measurement period. Corresponding drogue speeds and direction of travel were determined and tabulated. Drogue movements were compared with current meter data for possible correlation.

B. Temperature Measurements

1. Time-Continuous Temperature Measurements

Continuous time series temperature measurements were made concurrently with the current measurements. One recording thermograph (Figure 1.5) was attached directly beneath each current meter at all but the North Mooring (Location 25). The thermographs (ENDECO Type 109) recorded hourly averaged temperature on 16 mm film with a resolution of 0.1C and an accuracy of ±0.2C. The time constant of the instrument is 10 min. The thermographs were serviced simultaneously with the current meters with the replenishment of new batteries, film, and dessicant bags. One of the four thermographs was either lost or stolen, during the study, resulting in a partial loss of temperature data. The thermograph at the Offshore Surface Mooring was lost in August, but replaced in early September with the unit from the Offshore Deep Mooring. The Deep Mooring unit was not replaced.

Hourly averages of temperature versus time were plotted for each month and each location. Comparisons of thermograph data and current meter data were made to determine the relationship between speed and direction of water movement and temperature trend at each mooring location.

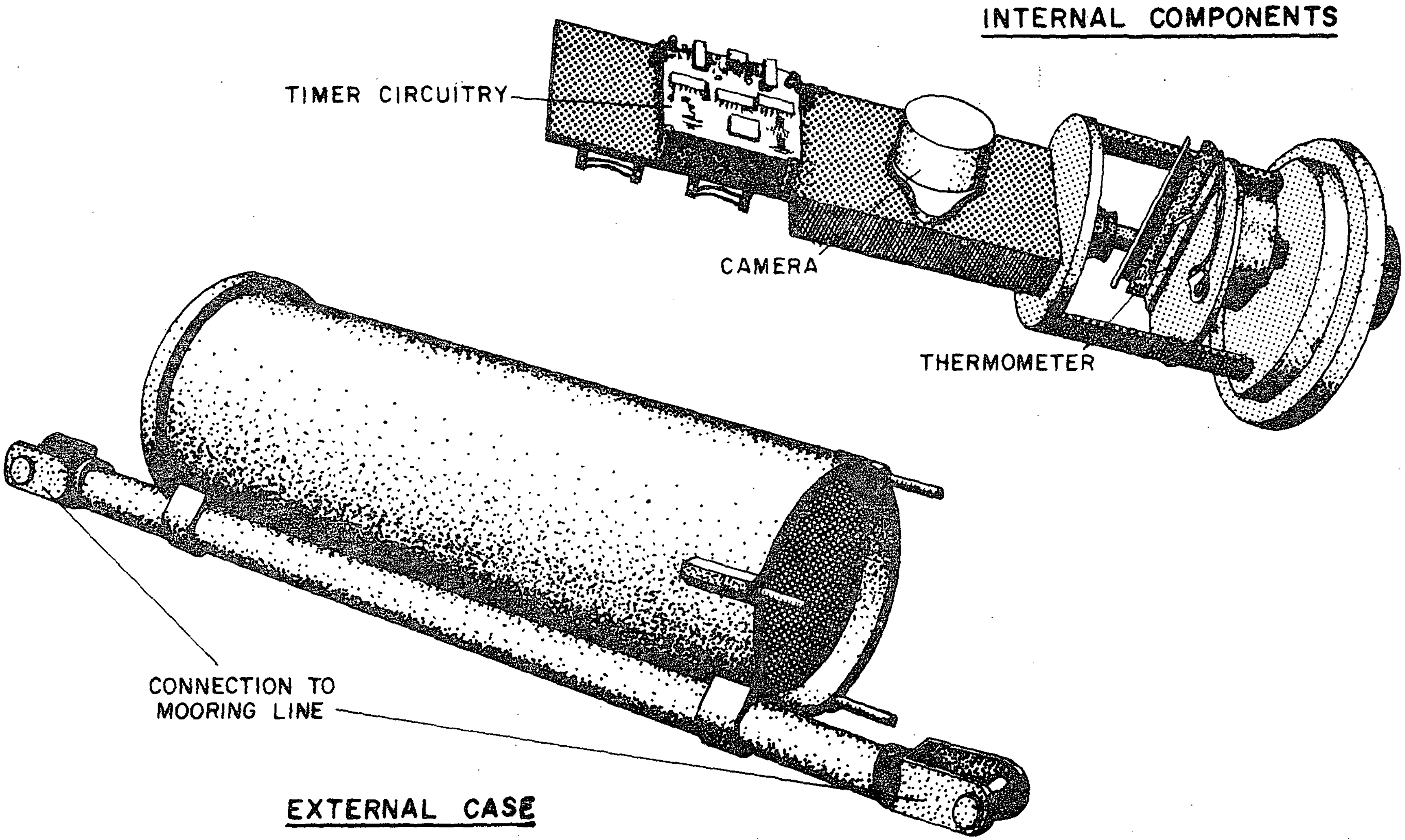


Figure 1.5 Recording thermograph (ENDECO Type 109) used for time-continuous temperature recording in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

2. Monthly Temperature Profile Measurements

Thermal structure of the water mass in the vicinity of the KNPP was determined at least once each month using a thermistor temperature probe (Montedoro-Whitney Corporation, Model TC-5B). This instrument provided a resolution of 0.03C and an accuracy to within ±0.1C.

Temperature measurements were taken along four transects perpendicular to the shoreline (Figure 1.6). Along each transect, water temperature was measured at one meter depth intervals at each of the locations. Transects were located to best determine the vertical thermal structure of the water. These transects generally defined an area of 18 km^2. Vertical temperature profiles were plotted for each transect and isothermal contours were drawn. The position of measurement locations comprising the transects were determined by two shoreline transit bearings.

The thermal profile data were compared with the time-continuous current meter and temperature data for possible correlations. Temperature profile data were also used to check the accuracy of the thermographs.

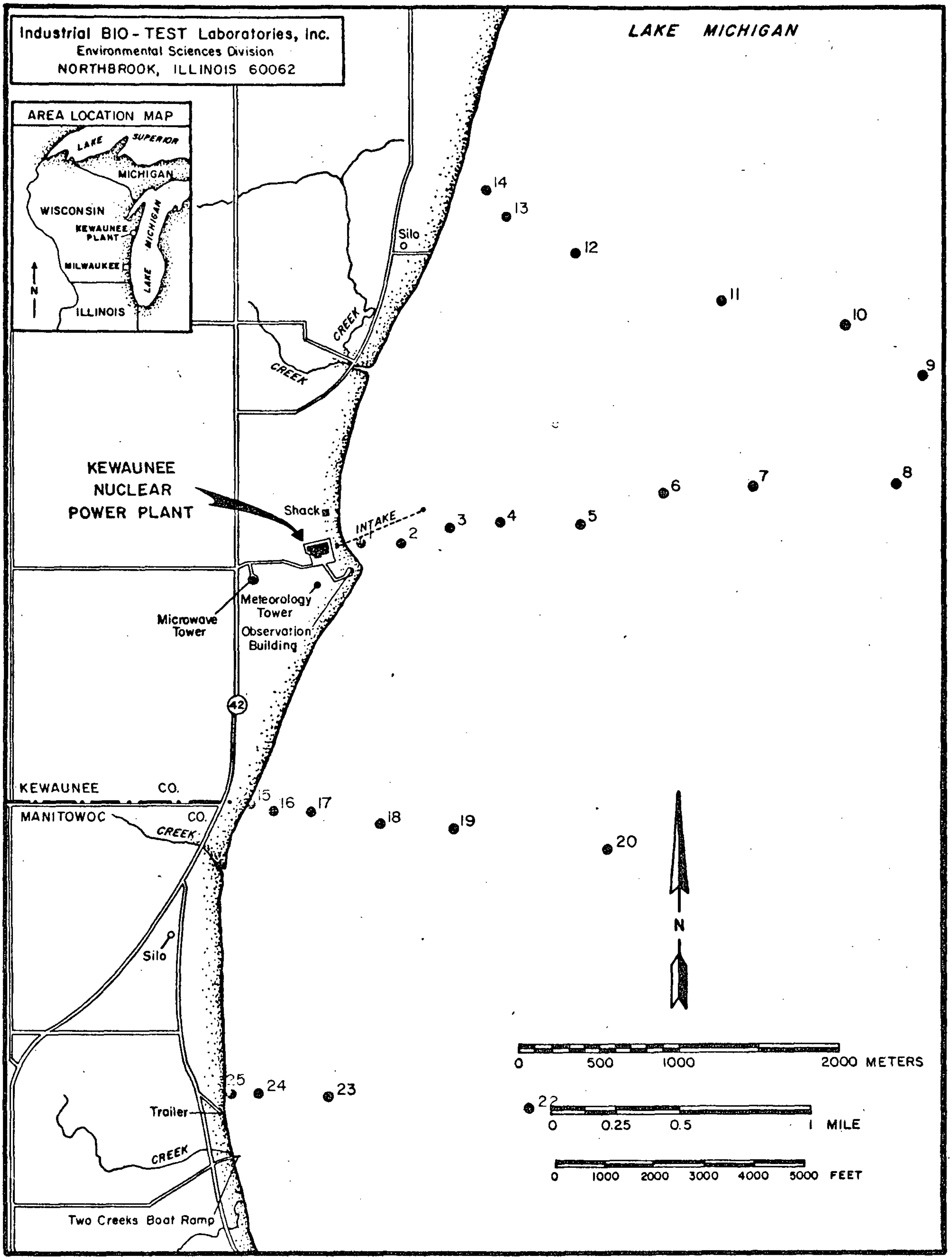


Figure 1.6 Location map showing the usual position of temperature profile measurements in Lake Michigan near the Kewaunee Nuclear Power Plant, 7 June 1973.

III. Results and Discussion

A. Current Measurements

1. Time-Continuous Current Meter Measurements

The time-continuous current data herein described represents a 72 percent return of valid data for the entire measurement program (excluding missing data due to lost equipment).

A visual comparison of the current speed data obtained at each location (Appendix 1-A) shows good correlation among the locations during each month. A typical example of the degree of speed correlation is shown in Figure 1.7. The fluctuations in speed as measured at each location were strongly correlated in time but differed slightly in magnitude. The speeds measured at the North Mooring were generally slightly faster than those at other locations. Typical speeds ranged from 0.1 to 0.4 ft/sec, and the maximum speed recorded was 1.2 ft/sec which occurred during December at the North Mooring. The correlation of speed fluctuation infers that the water motion in the vicinity of KNPP is spacially homogeneous and effectively moves as a single water mass. Some differences from the general direction of flow at an individual mooring were observed, but these are localized effects due to deflection caused by the bottom topography. The directional differences indicate a temporary interruption of the general water movement at a given location, but they are not necessarily indicative of a directional change in the overall flow of the water mass (cf. PROVECS in Appendix 1).

The PROVECS were formed by connecting the time series of velocity vectors for a current meter record. An example is presented in Figure 1.8. The vectors were connected head to tail and produce a diagram that resembles

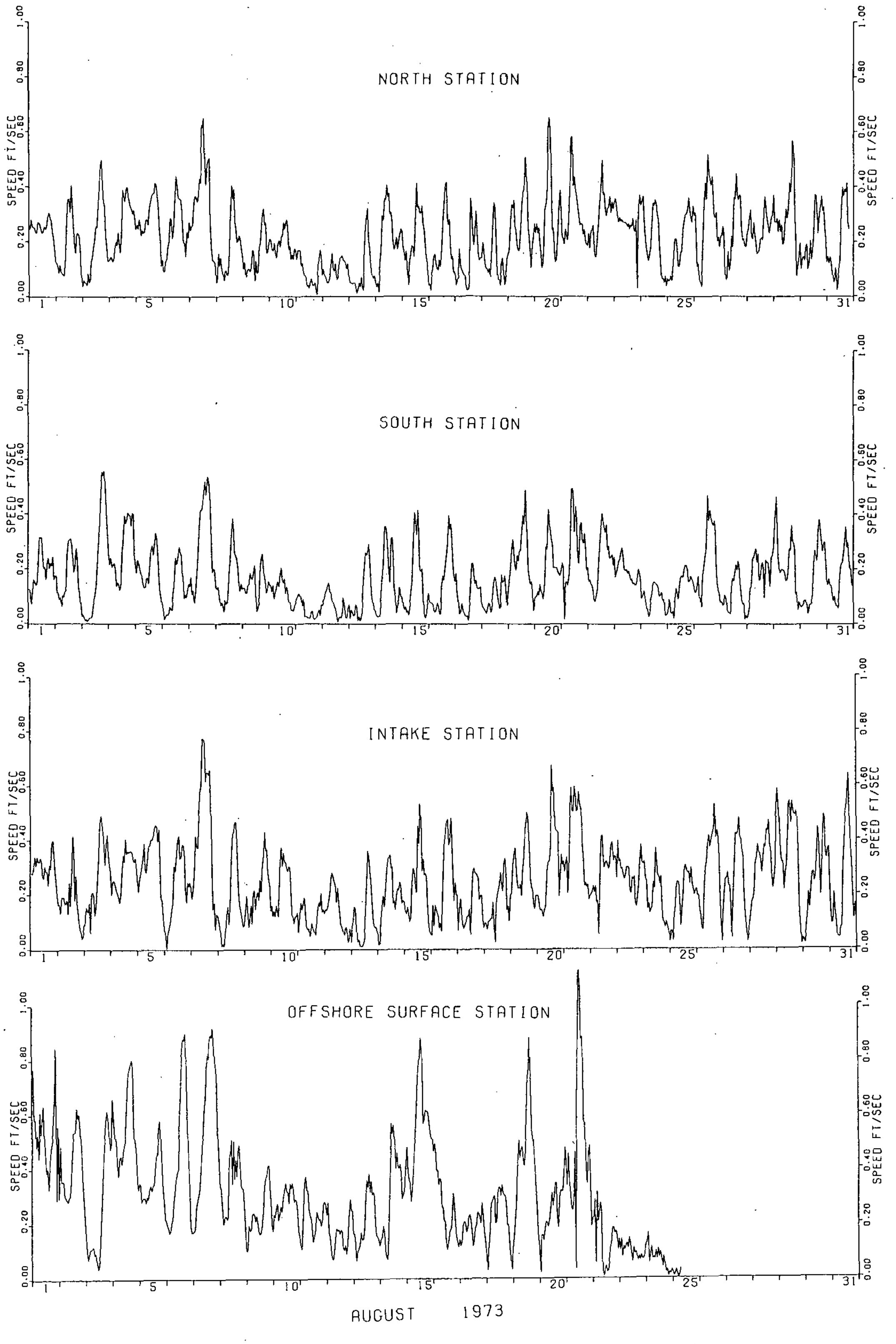


Figure 1.7 Time-continuous current speed measurements at each mooring location in Lake Michigan near the Kewaunee Nuclear Power Plant, August 1973.

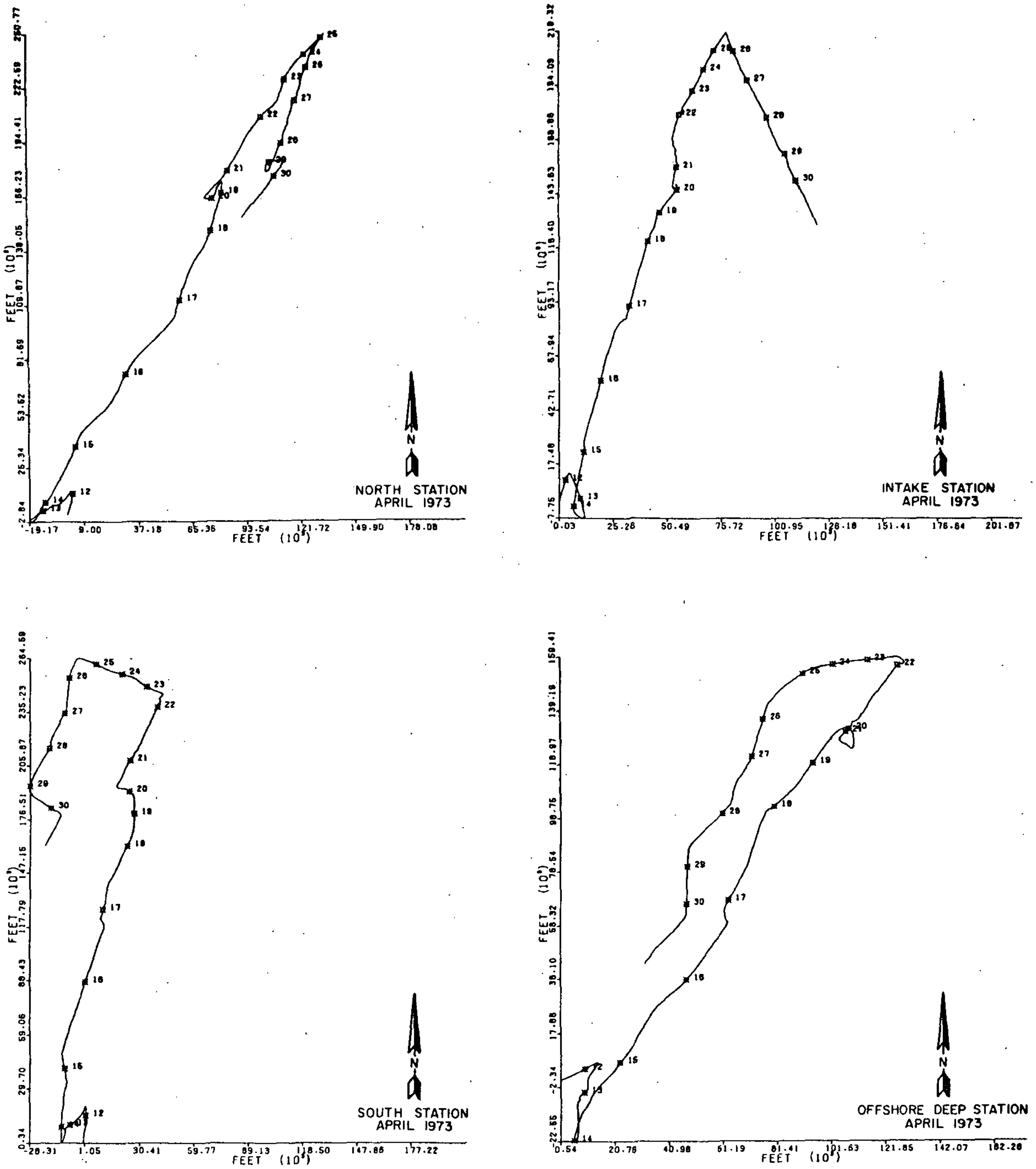


Figure 1.8 Progressive Vector Diagrams (PROVECS) of time-continuous measurements of currents in Lake Michigan near the Kewaunee Nuclear Power Plant, April 1973. Asterisks and adjacent numbers indicate the beginning and date of each measurement day.

the horizontal projection of a water particle trajectory. It should be kept in mind that a PROVEC depicts the history of water motion past a given point and is not a representation of a trajectory.

Intercomparison of the PROVECS for a given month permits determination of the relative velocity and direction of flow past each mooring location for any period chosen. The horizontal axis of each diagram indicates eastward (positive) and westward (negative) motion while the vertical scale indicates northward (positive) and southward (negative) motion. The data from each measurement location were plotted by beginning at the origin (0.0) and proceeding until the end of the time-continuous measurement. If a gap in the data was present, the plot of the succeeding portion of data was reinitiated at the origin and plotting continued in the normal manner. The asterisks and adjacent numbers on the plots indicate the beginning and date of each measurement day.

Close bunching of the asterisks infers slow current for that period whereas increased distance between asterisks infers faster current. For example, Figure 1.8 contains the PROVEC for April 1973. From the 15th to the 20th, current flow at all locations was relatively steady and towards the NNE. During this period the direction of flow was somewhat different among the four locations and is believed to be due to the bathymetry at each location. During the 22nd, the flow at the South and Offshore Deep Moorings abruptly changed directions to flow toward shore (from a previously shore-parallel direction) and the speed of flow slowed. The flow at the North and Intake Moorings during this time period did not change direction but it did slow somewhat. The flow then remained relatively uniform in speed and direction at all locations until the 25th, when abrupt changes in direction were recorded at the North and Intake Moorings and a somewhat more gradual directional change was recorded at the South and Offshore Deep Moorings.

Examination of the wind data collected as part of the meteorological monitoring program at the Kewaunee Nuclear Power Plant for the April measurement period provides insight into the forces responsible for the water movement. From the 15th to the 18th, winds at the 35 ft level of the KNPP meteorological tower were predominantly from the SSW and decreased in speed from 23 to 4 mph. At approximately 1800 hours on the 18th, winds shifted to blow from the NNE at approximately 5 mph. Winds continued to slowly shift from the NNE through the east to the SSE and ranged in speed from 5 to 12 mph until approximately 0800 hours on the 20th of April. The PROVEC for the Offshore Deep Mooring (Figure 1.8) clearly reflects the above described wind history in that the current appeared to flow with the wind. The North Mooring record also exhibits the influence of the wind pattern. The Intake and the South Mooring records indicate a change in flow, but the effect of the NNE wind is not as clearly reflected as in the other records. One explanation for the difference in flow at the South Mooring may be that the promontory deflected or slowed the water flow from its southward direction or as inferred in the AEC's Final Environmental Statement for KNPP (Atomic Energy Commission 1972), a gyre may have been created on the southern side of the promontory which impeded a significant direction change at the South Mooring. It is possible that interaction of the flow from the south or the north and the promontory was responsible for the difference in flow behavior at the Intake Mooring location.

Beginning at 0900 hours on the 20th of April, the winds slowly began to shift from the south and the southwest,and by 0300 hours on the 22nd they were blowing from the west and finally the NNW from which they continued to blow until 0600 hours on the 24th. The Offshore Deep Mooring record for the same time period shows strong direct correlation with the change of wind direction (Figure 1.8). As the wind blew offshore., the surface water moved along with it. In response to this loss of surface water, water from a depth beneath that which is directly affected by the wind moved shoreward to replace the lost surface water. This effect is commonly referred to as upwelling and it is this flow which was recorded from the 22nd to the 25th at the Offshore Deep and South Moorings. The flow recorded at the Intake and North Mooring locations during this period showed no significant change in direction in response to the wind shift described, but the speed did reduce with time as the wind continued to blow from the NNW. By approximately 0700 hours on 24 April, the wind had shifted to the NNE and continued to shift through the south and west to approximately the NNW by 0200 hours on the following day (25 April). The wind continued to blow in this direction for the next 36 hours before any significant change of direction occurred. A response to this 36-hour period of NNW winds was recorded at each mooring location.

To summarize this example, the PROVECS are useful in determining the type of flow recorded and in correlating the flow at different locations. A comparison of a number of these monthly diagrams with other data (such as wind and bathymetry) provides insight into the nature of the flow, its responsible forces, and its limiting factors.

A visual analysis, similar to that just described for April, of all the time-continuous current data obtained, with due consideration given to the available wind and bathymetric data, provided several useful observations discussed below.

The promontory offshore of the Plant is believed to play a major role in deflecting or otherwise interrupting the current flow within the area that it occupies. It was found that generally the current flow followed the bottom contours, a characteristic especially noticeable at the North and South Mooring locations.

The current records show that when generally northward flow occurred, it occurred simultaneously at all mooring locations; but when generally southward flow occurred, it did not occur simultaneously at all locations, probably due to the deflection of the flow toward the east by the presence of the promontory in the vicinity of the Intake Mooring. The net displacement of water past KNPP was generally shore-parallel to the north at a mean speed of approximately 0.08 ft/sec. The water circulation pattern within the vicinity of the Plant was strongly related to the local winds. However, a good statistical correlation could not be established due to insufficient wind data. Periods of upwelling or downwelling are difficult to distinguish using the current records alone (additional current meters, one near the surface and one near the bottom on the same mooring line would facilitate the identification of these phenomena).

Comparison of the Joint Frequency Tables of lake current speed and direction (Appendix 1-C) with those of wind speed and direction (Appendix 1-D) was made for April through July. It is difficult to make a statement which typifies the relationships that exist based on this small amount of data and because the data which comprise the wind and current tables are not necessarily those of simultaneous events. Data gaps occurred in both the wind and current records and for accurate correlations, simultaneously recorded data are necessary.

A comparison of the wind and current data on a day by day basis indicates that winds from the SSW produced lake current flow toward the NNE at all locations measured. Periods during which winds are generally easterly or westerly produce current of a different direction at each location (this effect is largely dependent upon the bottom topography, e.g. during May, when the wind was predominantly from the west, the net flow at the North Mooring was toward the NNE, that at the South and Offshore Deep Moorings was toward the SSW, and that at the Intake Mooring was toward the SSE.) Winds which blew from a generally northerly direction (NNE to NNW) produced southward flowing current at the North and South Moorings, but generally southeastward flow at the Intake Mooring.

2. Current Drogue Measurements

The drogue data were plotted (Appendix 1-E) and the corresponding speeds and direction of travel were determined and listed (Appendix 1-F). The data show, as do the time-continuous current measurements, that the water body in the vicinity of KNPP was generally spacially homogeneous in speed. The drogues at different locations often moved in slightly different directions, an effect which is believed due to the bottom topography. Speeds measured at the various depths were fastest at the surface and generally decreased with increasing depth.

A comparison of the drogue data with the available current meter and wind data (as measured by BIO-TEST personnel during the drogue studies) showed that when wind velocities were 10 mph or greater, the drogue speeds were often up to 0.4 ft/sec faster than those measured by the current meters. A difference in direction of water flow as determined by the drogues and the current meter measurements ranged between 10 and 50 degrees (the drogues generally moved in a direction to the right of that indicated by the current meters. The deflection of the cross vane drogue from the true direction of current flow has been mentioned by others. Monahan, et al. (1973) have observed the current cross vane to develop a rotational motion about its vertical axis in every tow tank test conducted. They feel that this slow spinning of the cross vane unit can induce the drogue to develop a component of motion in a direction normal to the direction of true current flow, similar to a weak "curve ball" in baseball. The speed of current flow as determined by the movement of the drogues was frequently greater than that determined by the current meters, and this difference increased with increasing wind speeds.

This infers that the drogues were somewhat sensitive to the wind, probably due to wind pressure on the drogue surface float.

It is difficult and of ambiguous statistical significance to make direct comparisons of drogue and current meter data except during those rare instances when the drogue physically moves past the current meter during a given study. In such a case, it is considerably more certain that the two devices are in fact measuring the same parcel of water. A water "parcel" is not the same as water "mass." Parcel is a small and local amount of the mass. Within a mass, there can be localized movements which are short lived and do not have a lasting or significant effect on the general movement of the encompassing water mass. Water that has moved past a moored instrument at a given time is not necessarily moving with the same speed or in the same direction once it has passed that mooring. Consequently, it is not surprising that differences occurred in these studies between flow determined by drogue studies and flow determined by current meter data. However, it is important to note that the results of the drogue and moored current meter studies are in relatively good agreement.

B. Temperature Measurements

1. Time-Continuous Temperature Measurements

The time-continuous temperature data herein described represents a 92 percent return of valid data for the entire measurement program (excluding missing data due to lost equipment).

The time-continuous temperature data (Appendix 1-G) show good correlation among the four locations. Fluctuations in temperature occurred almost simultaneously at all locations which further attests to the homogeniety of movement of the water body as indicated by the time-continuous current data. Maximum, minimum, and mean values of temperature from April through December 1973 are tabulated in Table 1.1. When making comparisons among the various locations, consideration must be given to the length of each record. Records of significantly different length contain data collected during different time periods and therefore cannot be directly correlated. Data in Table 1.1 show that the periods of greatest temperature range occurred during August ($\Delta T = 14C$), and that the greatest temperature range of all locations was measured at the Offshore Deep Mooring.

A comparison of the minimum temperatures recorded among the South, Intake and Offshore Surface Moorings shows that for records of approximately equal record length, with the exception of July, the South Mooring always had somewhat warmer minimum temperatures than all other locations. The mean and maximum temperatures recorded at all locations were highest during August; the mean temperatures among locations for each month (with the exception of the Offshore Deep Mooring) were generally within ±0.5C of one another.

A period of rapid temperature decrease occurred on 7 August and 13-14 October. These were periods of upwelling during which cold deep offshore water was brought toward shore to replace the surface water probably being displaced by the prevailing offshore winds. At the Intake, South and Offshore Deep Moorings during the August event the temperature showed an approximate decrease of 11, 8 and 13C respectively. Those decreases measured at the Intake and Offshore Surface Moorings during the October event were 5 and 7C respectively.

Table 1.1 Monthly means and ranges of time-continuous recordings of temperature in Lake Michigan near the Kewaunee Nuclear Power Plant in 1973.

Month	Mooring							
	Intake		South		Offshore Surface		Offshore Deep	
	Temperature (°C)	Record Length (hr)	Temperature (°C)	Record Length (hr)	Temperature (°C)	Record Length (hr)	Temperature (°C)	Record Length (hr)
April								
Mean	5.5	467	-[a]	-	3.7	467	-	-
Range	1.8- 8.7		-		1.3- 6.2		-	
May								
Mean	8.7	705	9.2	579	7.1	694	6.3	434
Range	6.0-12.2		7.2-12.9		5.0- 9.8		5.0- 8.1	
June								
Mean	9.2	703	9.4	719	10.2	85	6.9	720
Range	6.0-13.2		6.7-13.4		9.0-12.2		5.0-11.5	
July								
Mean	12.6	741	12.4	742	10.5	418	10.1	742
Range	7.9-18.6		7.0-17.9		6.9-14.5		5.6-18.8	
August								
Mean	15.3	744	15.5	744	-	-	13.7	744
Range	7.0-20.6		7.1-21.1		-		5.0-20.2	
September								
Mean	12.8	617	13.1	636	16.2	300	7.2	211
Range	7.1-17.1		8.1-17.1		14.3-17.5		5.3- 9.4	
October								
Mean	11.1	732	8.4	370	10.8	732	-	-
Range	6.7-15.8		6.8-10.4		5.6-15.5		-	
November								
Mean	6.0	720	6.0	720	6.4	720	-	-
Range	4.1- 8.7		4.2- 7.3		4.8- 9.2		-	
December								
Mean	3.6	302	3.5	301	4.0	301	-	-
Range	1.5- 5.1		1.9- 5.8		2.2- 4.9		-	

[a] No data were collected during this time period.

A period of rapid temperature increase occurred on 14 August and 13-14 September. The approximate increase in temperature at the Intake, South, and Offshore Deep Moorings for the August event was 8, 6 and 8C respectively. Those increases for the Intake and South Moorings during the September event were approximately 6C each. Although it cannot be confirmed due to the unavailability of wind data at the KNPP site, it is believed that the rapid temperature increase (especially during the August period) was the result of diminishing offshore winds and a return of the warmer displaced water to its previous condition. This phenomenon may also be thought of as downwelling if it is the result of onshore winds (or if the density of surface water were to become greater than the underlying water).

Fluctuations in the temperature records of 16-17 hr, which is near the inertial period of 17.5 hr, occurred frequently at all locations.

There appears to be a 5-6 day cyclic phenomenon in the data which is especially noticeable in the South and Intake Mooring records for June and July. A brief examination of barometric pressure data collected at Green Bay, Wisconsin, suggests a possible relationship between the temperature cycle and the barometric pressure. Further investigation into this matter may be beneficial.

Monthly temperature ranges recorded at the Intake Mooring were greater more frequently than at the other locations.

The minimum temperature value recorded in mid-April (1.8C) is approximately the same value as that recorded in mid-December and is near the minimum value which is expected to occur. This suggests that the April to December temperature measurement program is quite sufficient to be representative of an annual temperature cycle.

2. Monthly Temperature Profile Measurements

Plots of the temperature profile data are presented in Appendix 1-H. Within a three-week period from 13 April to 3 May, the water body warmed from temperatures of approximately 2C to 8C while maintaining a nearly vertical isothermal structure. By 7 June, some 35 days later, the maximum temperature measured was only 9.5C, but the thermal structure pattern had changed to one of predominantly horizontal isotherms. The 18 July survey showed that near shore surface waters had warmed to nearly 13C and that a stronger vertical temperature gradient (2 C/m) had begun to form at a depth of 3m. A maximum monthly measured surface temperature of 18.5C for the entire study was observed during August which was accompanied by a 5-7C temperature difference from the surface to the bottom at the 20-ft depth contour. (The maximum temperature recorded by the continuously recording thermographs was 21C on 3 August at the South Mooring.) During the period from September 14 to October 16, the thermal structure reverted from a horizontal to a vertical one. During this one month period, the temperature throughout the water column decreased approximately 8C to between 6 and 8C. The overall temperature had further decreased approximately 1-2C by 19 November, and by 12 December the temperature had decreased another 3C to a measured average temperature of 2.7C throughout the water column.

A comparison of measurements from each monthly survey shows that the measurement area was relatively homogeneous horizontally for any given depth (within ±2.0C throughout the study area during each survey), with the exception of the measurements made on 18 July when apparent upwelling caused the southernmost transect to be approximately 4C cooler than those to the north of it.

The thermal profile data indicate that the temperature changes that occur from month to month occur in a relatively similar fashion at all locations. A comparison of the temperature profile data with the time-continuous current and temperature data did not provide any useful correlations. These comparisons did, however, show that the thermographs were measuring temperature accurately. As stated previously, it is difficult to identify periods of upwelling and downwelling from the current meter records alone. Such phenomena were visible, however, in the temperature profile data (e.g. 7 June and 28 August).

IV. Summary and Conclusions

1. The data collected describe the spatial and temporal near shore circulation and temperature distribution in the vicinity of KNPP for the measurement period and provide temperature estimates for the non-measurement period (November-April).

2. The data collected was sufficiently representative to provide useful input into the predictive aspects of the KNPP thermal plume model.

3. The water mass movement in the area of KNPP is spatially homogeneous in speed, but the direction of flow is dependent upon the bottom topography and the prevailing local winds.

4. Northward flowing currents generally occur simultaneously at all locations whereas southward flowing currents do not generally occur simultaneously at all locations.

5. The promontory in the region of the condenser cooling water intake plays a major role in the general water circulation in the vicinity of the KNPP.

6. The net displacement of water past the KNPP was generally shore-parallel and to the north at an approximate mean velocity of 0.08 ft/sec.

7. Periods of greatest temperature range occurred during August. This range was found to be as great as 14C.

8. Temperature minimums recorded at the South Mooring were always warmer than those measured at other locations.

9. A maximum temperature of 20.6C was recorded during August in the area of the intake, and maximum temperatures of 20.2 and 21.0C were

recorded during August at the Offshore Deep and South Mooring locations respectively.

10. Monthly mean temperatures at all locations differed by 0.5C or less.

11. Rapid temperature changes due to upwelling and downwelling in the vicinity of the condenser cooling water intake were found to be as great as 11C in a 24 hr period at an approximate depth of 8 ft.

12. Fluctuations in the temperature records which were near the inertial period occurred frequently.

13. Sufficient wind data recorded simultaneously with the current data were unavailable. This limited the establishment of definitive and predictive relationships of water circulation based upon knowledge of the wind characteristics.

14. There is sufficient evidence to suggest a more thorough investigation of the circulation and temperature structure in the vicinity of the promontory might be warranted. Such a study would attempt to determine the presence of gyres or other phenomena which might occur and act as a heat sink by trapping a portion of the thermal discharge.

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Chapter 2

WATER CHEMISTRY AND BACTERIOLOGY

Michael J. Gara and John E. Hawley

PREOPERATIONAL THERMAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR KEWAUNEE NUCLEAR POWER PLANT

THIRD ANNUAL REPORT
January-December 1973

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Chapter 2

WATER CHEMISTRY AND BACTERIOLOGY

Michael J. Gara and John E. Hawley

I. Introduction

This chapter contains the results of the third year of preoperational monitoring of the quality (physical, chemical and bacteriological) of Lake Michigan water in the vicinity of the Kewaunee Nuclear Power Plant (KNPP). The specific objectives of the 1973 study were:

1. to determine the existing water quality in the vicinity of KNPP;
2. to compare the existing water quality with state standards adopted by the Wisconsin Department of Natural Resources and contained in the Wisconsin Administrative Code;
3. to determine the seasonal and spatial distribution of those parameters measured;
4. to establish from bacteriological and biochemical oxygen demand (B.O.D.) data whether or not domestic sewage or agricultural wastes may be present in the waters near KNPP;
5. to determine the similarity among the water masses which make up the study area based on temperature and dissolved oxygen (D.O.) profile data;
6. to compare the 1973 data with those collected during the previous preoperational monitoring programs conducted in 1971 and 1972; and
7. to determine total residual chlorine levels at different points in

the circulating water system, under different operating conditions of the chlorination system.

The closest major tributary which could affect the water quality in the vicinity of the KNPP site is the Kewaunee River located approximately 8 miles north of the Plant. Additional samples were collected from the Kewaunee River during three sampling periods to determine the influence of this water source on Lake Michigan water quality at KNPP.

II. Field and Analytical Procedures

Duplicate water samples for chemical and bacteriological analyses were collected monthly from April through November, 1973, at nine lake sampling locations (Figure 1, Introduction) using a non-metallic Van Dorn sampler. Chemistry samples collected at three locations along the 10-ft contour were taken at mid-depth; samples collected at three locations along the 20-ft contour were taken 1 m below the surface and 1 m above the bottom; and samples collected at three locations along the 40-ft contour were taken 1 m below the surface, at mid-depth, and 1 m above the bottom. The chemical parameters measured and their respective analytical methods, preservation techniques, detection limits, and references are presented in Table 2.1.

Temperature and D.O. profile measurements were taken at the surface and at every meter of depth at 19 lake sampling locations (Figure 1, Introduction). The physical measurements described in Table 2.2 were recorded at the nine water chemistry locations at the time of sampling.

Duplicate water samples were collected from the Kewaunee River at the Highway 42 bridge in April, May and June. All the parameters listed in Table 2.1 were measured in these samples.

Two different methods of measuring iron concentrations were utilized during this study due to a wide range of concentrations encountered. When iron concentrations exceeded 0.1 mg/l, an atomic absorption spectrophotometry, direct aspiration method was used. The preconcentration technique of Fishman and Midgett (1968) was employed for concentrations below 0.1 mg/l. The first

Table 2.1 Analytical methods for chemical parameters **measured in samples** collected from Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant during 1973.

Parameter	Method and Reference	Preservation Technique	Detection Limit
Alkalinity, total	Method 102[a]	None required	1 mg/l-$CaCO_3$
Alkalinity, phenolphthalein	Method 102[a]	None required	1 mg/l-$CaCO_3$
Ammonia	Gas diffusion electrode[b]	$HgCl_2$[c]	0.01 mg/l-N
Arsenic	AAS/AsH_3[d]	HNO_3[e]	1 µg/l
Bacteria, standard plate count	Techniques for micro-biological analysis (20.0C and 35.5C)[f]	Sterile[g]	0 organisms/ 100 ml
Bacteria, total coliform	Method 408A[a]	Sterile[g]	0 organisms/ 100 ml
Bacteria, fecal coliform	Method 408B[a]	Sterile[g]	0 organisms/ 100 ml
Bacteria, fecal streptococci	Method 409B[a]	Sterile[g]	0 organisms/ 100 ml
Biochemical oxygen demand (5-day)	Method 219[a]	B.O.D. water sealed bottle, refrigerated	0.5 mg/l
Boron	Dianthrimide method[h]	None required	0.01 mg/l with 10 ml sample size
Cadmium	AAS/Chelation[i]	HNO_3[e]	0.1 µg/l
Calcium	AAS/DA[j]	HNO_3[e]	2 µg/l
Chemical oxygen demand	Low level method[k]	Glass container, refrigerated	0.1 mg/l

Table 2.1 (continued)

Parameter	Method and Reference	Preservation Technique	Detection Limit
Chloride	Mercuric nitrate method 112B[a]	None required	0.5 mg/l
Chlorine demand	Method 115A[a] then amperometric method 114B[a]	None required	0.01 mg/l
Chlorine, total	Amperometric method 114B[a]	Measured at sampling location	0.01 mg/l
Chromium, total	Digestion/AAS/Chelation[i]; beginning June 1973, Flameless AAS/HGA[l]	HNO_3[e]	1 µg/l
Color, true	Colorimetric method 118[a]	None required	1 unit
Conductance, specific	Method 154[a]	None required	1 µmho/cm
Copper	AAS/Chelation[i]	HNO_3[e]	0.1 µg/l
Fluoride	Specific ion electrode[m]	None required	0.01 mg/l
Hardness, total	Sum of Ca and Mg. AAS/DA[j]	-	1 mg/l-$CaCO_3$
Hydrazine	Method D 1385[n]	HCl, glass container	4 µg/l
Iron	AAS/Chelation[i]	HNO_3[e]	1 µg/l
Iron, total	AAS/DA[j]	HNO_3[e]	0.01 mg/l
Lead	AAS/Chelation[i]	HNO_3[e]	1 µg/l
Magnesium	AAS/DA[j]	HNO_3[e]	1 µg/l

Table 2.1 (continued)

Parameter	Method and Reference	Preservation Technique	Detection Limit
Manganese	AAS/Chelation[o]; beginning June 1973, Flameless AAS/HGA[l]	HNO_3[e]	1 µg/l
Mercury	Flameless AAS[k]	HNO_3[e]	0.05 µg/l
Morpholine	Method D 1942[n]; beginning June 1973, spectrophotometric method[p]	None required	1 mg/l 0.5 mg/l
Nickel	AAS/Chelation[i]	HNO_3[e]	1 µg/l
Nitrate	Brucine method 213C[a]	$HgCl_2$[c]	0.01 mg/l-N
Nitrite	Sulfanilamide method[q]	$HgCl_2$[c]	0.2 µg/l-N
Organic carbon, total	Beckman Model 915 Carbonaceous Analyzer	HCl to pH 2	1 mg/l
Organic nitrogen, total	Method 135[a] and phenate method 132C[a]	$HgCl_2$[c]	0.01 mg/l
Orthophosphate, soluble	Ascorbic acid method[q]	Filtration[r]	1 µg/l-P
Oxygen, dissolved	Dissolved Oxygen Meter, standardized by method 218B[a]	Measured at sampling location	0.1 mg/l
Oxygen, saturation	Calculated from D.O. and temperature data[s]	-	Expressed as percent
pH	Glass electrode method 144A[a]	None required	0.1 pH
Phosphorus, total	Method 223C[a] then ascorbic acid method[q]	None required	1 µg/l-P
Potassium	AAS/DA[j]	HNO_3[e]	5 µg/l

Table 2.1 (continued)

Parameter	Method and Reference	Preservation Technique	Detection Limit
Residue, filtrable (total dissolved solids)	Method 148B[a]	None required	1 mg/l
Residue, non-filtrable (total suspended solids)	Method 148C[a]	None required	1 mg/l
Residue, total (total solids)	Method 148A[a]	None required	1 mg/l
Silica, soluble	Method 151C[a]	Filtration[r]	0.01 mg/l-SiO_2
Sodium	AAS/DA[j]	HNO_3[e]	2 µg/l
Sulfate	Turbidimetric method 156C[a]	Filtration prior to analysis	5 mg/l
Turbidity	Hach Model 2100A Turbidimeter	None required	1 J.T.U.
Zinc	AAS/Chelation[i]	HNO_3[e]	1 µg/l

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[a] A.P.H.A., A.W.W.A., and W.P.C.F. 1971. Standard methods for the examination of water and wastewater. 13th ed. Am. Public Health Assn., Washington D.C. 874 pp.

[b] Thomas, R. F., and R. L. Booth. 1973. Selective electrode measurement of ammonia in water and wastes. Environ. Sci. Technol. 7: 523-526.

[c] 40 mg $HgCl_2$ added to one liter of sample, refrigerated. Howe, L. H. III, and C. W. Holley. 1969. Comparisons of mercury (II) chloride and sulfuric acid as preservatives for nitrogen forms in water samples. Environ. Sci. Technol. 3: 478-481.

[d] Perkin-Elmer Corporation. 1972. Instructions for high sensitivity arsenic-selenium sampling system #303-0849. Norwalk, Connecticut.

[e] 5 ml concentrated HNO_3 added to two liters of sample.

Table 2.1 (continued)

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[f] Millipore Corporation. 1967. Techniques for microbiological analysis. ADM-40. Bedford, Massachusetts.

[g] Sterile conditions, refrigerated, with 1 ml/l 10% $Na_2S_2O_3$ added.

[h] Levinson, A. A. 1971. An improved dianthrimide technique for the determination of boron in river waters. Water Res. 5: 41-42.

[i] Fishman, M. J., and M. R. Midgett. 1968. Extraction techniques for the determination of cobalt, nickel, and lead in freshwater by atomic absorption. Pages 230-236 <u>in</u> Gould, R. F. (Ed.), Trace inorganics in water. Amer. Chem. Soc., Washington, D. C.

[j] Atomic Absorption Spectrophotometry/Direct Aspiration.

[k] Environmental Protection Agency. 1971. Methods for chemical analysis of water and wastes. Water Quality Office, Analytical Quality Control Laboratory, Cincinnati, Ohio. 312 pp.

[l] Flameless Atomic Absorption Spectrophotometry/Heated Graphite Atomizer. Perkin-Elmer Corporation. 1972. Perkin-Elmer analytical methods for flameless atomic absorption spectroscopy with the heated graphite atomizer HGA-72. Bodenseewerk Perkin Elmer & Co. GmbH, Uberlingen, Federal Republic of Germany. 13 pp.

[m] Orion Research, Inc. 1970. Instruction Manual. Cambridge, Massachusetts.

[n] American Society for Testing and Materials. 1971. 1971 Book of ASTM standards. Part 23. Water: atmospheric analysis. Philadelphia, Pa. 936 pp.

[o] The same as footnote i, but modified pH and extraction technique.

[p] Stevens, W.H., and K. Skov. 1965. A rapid spectrophotometric method for determining parts per million of morpholine in boiler water. Analyst. 90: 182-183.

[q] Strickland, J.D.H., and T.R. Parsons. 1972. A practical handbook of seawater analysis. Bull. Fish. Res. Bd. Canada. 167. 310 pp.

[r] Immediate filtration (Millipore HA 0.45 μ), refrigerated.

[s] Elmore, H.E., and T.W. Hayes. 1960. The solubility of atmospheric oxygen in water. Jour. Sanitary Eng. Div. ASCE. 86: 41-53.

NOTE

Pages 10 and 24 of Chapter 2 were missing from the archived document and are not included in this enclosure.

Table 2.2 Physical measurements and instruments used in the vicinity of the Kewaunee Nuclear Power Plant during 1973.

Measurement	Instrument
Air Temperature	
Wet bulb	Bendix Psychrometer
Dry bulb	Model 566
Relative Humidity	Bendix Centigrade Psychrometer Slide Rule
Wind	
Direction	Field Observer
Velocity	Dwyer Wind Meter
Cloud Cover	Field Observer
Water Temperature	Whitney Thermistor Thermometer Model TC-5A
Dissolved Oxygen	Beckman Dissolved Oxygen Meter

Lake Michigan were taken at a depth of one-meter using a non-metallic Kemmerer water sampler.

Samples were collected at all locations twenty and ten minutes prior to chlorination, at the start of chlorination, five minutes after the initiation of chlorination and then every ten minutes until the termination of chlorination. Total residual chlorine was determined by amperometric titration (Table 2.1).

Four experiments were performed on 19 and 20 June 1973. The operating conditions of the chlorination system during each experiment were as follows:

1. During Experiment I, the chlorine feed was calculated to produce a 0.1 mg/l total residual chlorine at the point of discharge into Lake Michigan. Circulating water pumps 1A and 1B were in operation as was the recirculating water pump;

2. During Experiment II, the chlorine feed was set at a maximum value. Circulating water pumps 1A and 1B were in operation as was the recirculating water pump;

3. During Experiment III, the chlorine feed was set at a reduced level. Circulating water pump 1A was turned off and pump 1B was in operation. The recirculating water pump was in operation but was turned off at 1005 because of overheating. The chlorine feed rate was also reduced at 0925 because residual chlorine values in the discharge were too high; and

4. During Experiment IV, the chlorine feed rate was varied to achieve a 0.1 mg/l residual value. Circulating water pumps 1A and 1B were in operation but the recirculating water pump was not operational.

III. Results and Discussion

The data from samples collected and analyzed during 1973 are contained in Appendix 2. Included are results of analysis of chemical and bacteriological samples, physical and meteorological data from each sampling location, and vertical temperature and dissolved oxygen profiles.

A. Comparison with State Water Quality Standards

Presented in Table 2.3 are the water quality standards adopted by the Wisconsin Department of Natural Resources, as contained in the Wisconsin Administrative Code, Chapter NR102, September 1973. These Lake Michigan standards are for public water supplies, recreational use, and for fish and other aquatic life. Table 2.3 includes the number of samples which exceeded the established standards during the study.

The measured values for Lake Michigan water quality parameters in the vicinity of KNPP were within the limits of the established standards with few exceptions. Values which were not within limits were those for turbidity and iron. Values for these parameters are weather dependent with high values resulting when wave action causes increased bottom scouring. A majority of the standards, including those for iron and turbidity, are also Public Health Service drinking water standards and refer only to water which has been appropriately treated for consumption. Since adequate clarification of these waters for drinking purposes would greatly reduce both iron and turbidity values, these high values commonly encountered should not be judged as being indicative of poor water quality.

Table 2.3. Existing water quality standards of the State of Wisconsin applicable to Lake Michigan near the Kewaunee Nuclear Power Plant.

Parameters	Existing Standards^{a}	Number of Samples which exceeded the Standards	Remarks
Temperature	89F (37.1C)^{b}	0	Upper limit
Dissolved Oxygen (mg/l)	5.0^{b}	0	Lower limit
pH	6.0-9.0^{b}	0	
Chloride (mg/l)	250^{c}	0	Upper limit
Fluoride (mg/l)	0.8-1.7^{c}	0	PHS standards are temperature dependent Grounds for rejection
Sulfate (mg/l)	250^{c}	0	Upper limit
Residue, filtrable (total dissolved solids) (mg/l)	750^{d}	0	Upper limit
Turbidity (J.T.U.)	5^{c}	85	Upper limit
Nitrate (mg/l)	45^{c}	0	Upper limit
Bacteria, fecal coliform (No./100 ml)	400 as a geometric^{e} mean for more than 10% of all samples during any month	0	Upper limit
Color, true (units)	15^{c}	0	Upper limit
Iron (mg/l)	0.3^{c}	26	Upper limit
Manganese (µg/l)	50^{c}	0	Upper limit
Lead (µg/l)	50^{c}	0^{f}	Upper limit - Grounds for rejection
Copper (µg/l)	1000^{c}	0	Upper limit
Zinc (µg/l)	5000^{c}	0	Upper limit
Chromium, total (µg/l)	50^{c} (Cr $^{+6}$)	0	Upper limit - Grounds for rejection
Cadmium (µg/l)	10^{c}	0	Upper limit - Grounds for rejection

Table 2.3. Continued.

Parameters	Existing Standards[a]	Number of Samples which exceeded the Standards	Remarks
Arsenic (µg/l)	10[c] 50[c]	0	Upper limit - Grounds for rejection

[a] Existing standards contained in the Wisconsin Administrative Code, Chapter NR102, September 1973.
[b] Standard for fish and other aquatic life.
[c] Public Health Service Drinking Water Standards incorporated into the existing water quality standards of the State of Wisconsin for public water supplies. Public Health Service, U.S. Department of Health, Education and Welfare, Washington D. C., 1962, 61pp.
[d] Standard for public water supply.
[e] Standard for recreational use waters.
[f] Lead values in Appendix 2 which exceed the Standards are due to contamination.

B. Summary of Data from the Kewaunee River

In the previous year's study of Lake Michigan (Industrial BIO-TEST Laboratories, Inc. 1973) several anomalous values for different parameters, notably filtrable residue and its related constituents, were observed at some locations. In addition, a matrix interference in the determination of boron was observed for the same set of samples. To determine whether waters entering Lake Michigan from the Kewaunee River approximately 8 miles north of the Plant may have been responsible for these inconsistencies, water samples were collected from the river in April, May and June.

The water quality of the river (Table 2.4) varied considerably during the three months it was studied, probably due to fluctuations in river flow. Nearly all of the water quality data for the Kewaunee River were higher than for Lake Michigan waters. Aquatic nutrients, metals and indicators of organic and oxidizable materials, indicated that the river was more eutrophic than Lake Michigan and could serve as a possible source of the anomalous data observed. However, an inspection of the spatial distribution of the data from the study area, in relation to the direction from which any influence would come, indicated that it was unlikely that the discharge of the Kewaunee River was affecting the water quality of the study area during 1973.

C. Temperature, Dissolved Oxygen and Oxygen Saturation

Temperature values increased steadily from April to August and decreased thereafter, exhibiting a range for the period April through November of 1.3 to 18.8 C (Table 2.5). Generally, temperature values were higher than

Table 2.4. Summary of water quality data collected from the Kewaunee River from May through July, 1973.

Parameter	Replicate	May	June	July
pH	A	8.2	7.9	8.0
	B	8.2	7.9	8.0
Alkalinity, total (mg/l-$CaCO_3$)	A	282	179	132
	B	284	181	130
Alkalinity, phenolphthalein (mg/l-$CaCO_3$)	A	0	0	0
	B	0	0	0
Calcium (mg/l)	A	69	51	44
	B	69	52	44
Magnesium (mg/l)	A	35.0	20.0	15.0
	B	35.0	20.0	15.5
Hardness, total (mg/l-$CaCO_3$)	A	316	209	172
	B	316	212	174
Chloride (mg/l)	A	17.0	9.5	9.4
	B	22.0	9.5	9.9
Fluoride (mg/l)	A	0.11	0.15	0.11
	B	0.13	0.15	0.11
Sulfate (mg/l)	A	25.0	20.8	18.0
	B	27.5	19.2	16.8
Sodium (mg/l)	A	8.6	6.7	5.0
	B	8.7	6.5	5.2
Potassium (mg/l)	A	3.1	2.0	1.7
	B	3.1	2.0	1.7
Conductance, specific (μmhos/cm)	A	605	419	341
	B	607	419	341
Residue, filtrable (total dissolved solids) (mg/l)	A	351	260	204
	B	353	258	210
Residue, nonfiltrable (total suspended solids) (mg/l)	A	15	24	14
	B	15	20	14
Residue, total (total solids) (mg/l)	A	366	284	218
	B	370	278	224
Turbidity (J.T.U.)	A	6	8	-[a]
	B	7	8	-[a]
Orthophosphate, soluble (mg/l-P)	A	0.073	0.041	0.014
	B	0.079	0.037	0.015
Phosphorus, total (mg/l-P)	A	0.11	0.13	0.079
	B	0.12	0.13	0.087
Ammonia (mg/l-N)	A	0.11	0.06	0.03
	B	0.12	0.05	0.04
Nitrate (mg/l-N)	A	0.75	0.35	0.19
	B	0.65	0.41	0.17
Nitrite (mg/l-N)	A	0.016	0.015	0.0063
	B	0.016	0.016	0.0070
Organic nitrogen, total (mg/l-N)	A	1.1	0.92	0.41
	B	1.0	1.1	0.61
Silica, soluble (mg/l-SiO_2)	A	1.2	2.5	0.39
	B	1.1	2.2	0.46

Parameter	Replicate	May	June	July
Bacteria, standard plate count at 20 C (No./100 ml)	A	240000	940000	730000
	B	350000	2600000	1000000
Bacteria, standard plate count at 35 C (No./100 ml)	A	90000	1900000	28000
	B	290000	15000000	110000
Bacteria, total coliform (No./100 ml)	A	3500	3200	3600
	B	2500	2700	3500
Bacteria, fecal coliform (No./100 ml)	A	8	46	12
	B	8	110	20
Bacteria, fecal streptococci (No./100 ml)	A	23	30	6
	B	23	24	4
Biochemical oxygen demand (5 day) (mg/l)	A	3.1	2.7	2.3
	B	2.7	3.0	2.5
Chemical oxygen demand (mg/l)	A	29.0	25.4	16.4
	B	29.0	27.3	12.2
Organic carbon, total (mg/l)	A	16	8	11
	B	10	10	14
Hydrazine (μg/l)	A	<4	<4	<4
	B	<4	<4	<4
Morpholine (mg/l)	A	<0.5	<0.5	<0.5
	B	<0.5	<0.5	<0.5
Color, true (units)	A	32	16	7
	B	32	16	9
Iron (mg/l)	A	0.28	0.38	0.21
	B	0.27	0.36	0.22
Manganese (μg/l)	A	31	26	29
	B	31	23	29
Mercury (μg/l)	A	0.10	<0.05	0.10
	B	0.05	<0.05	0.09
Lead (μg/l)	A	4	3	13
	B	5	3	5
Copper (μg/l)	A	2.6	2.4	1.8
	B	1.7	3.0	2.3
Zinc (μg/l)	A	7	16	11
	B	6	10	10
Chromium, total (μg/l)	A	2	3	3
	B	2	3	3
Cadmium (μg/l)	A	1.1	0.5	<0.1
	B	0.1	0.1	0.2
Nickel (μg/l)	A	<1	1	<1
	B	1	<1	<1
Arsenic (μg/l)	A	2	<1	1
	B	2	1	1
Boron (mg/l)	A	0.10	0.07	0.04
	B	0.02	0.04	0.04

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[a] Analyses not performed.

Table 2.5. Yearly means and ranges for temperature, dissolved oxygen and oxygen saturation values in samples collected from Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant in 1973.

Location		Temperature (°C)	Dissolved Oxygen (mg/l)	Oxygen Saturation (%)
2 Mid	mean	11.3	10.7	96
	range	2.2 - 17.5	8.1 - 13.2	70 - 109
7 Top	mean	11.0	10.7	97
	range	2.0 - 17.2	8.1 - 13.0	70 - 111
7 Bottom	mean	10.2	10.4	93
	range	2.0 - 16.6	7.8 - 12.9	67 - 109
11 Mid	mean	11.0	10.6	96
	range	1.9 - 17.2	8.7 - 12.7	76 - 111
12 Top	mean	11.0	10.7	96
	range	1.9 - 17.2	8.8 - 12.8	76 - 111
12 Bottom	mean	9.9	10.4	91
	range	1.8 - 16.7	8.1 - 12.7	71 - 112
14 Top	mean	11.0	10.7	97
	range	1.5 - 18.8	8.7 - 12.7	76 - 108
14 Mid	mean	10.5	10.6	95
	range	1.4 - 16.8	8.5 - 12.8	76 - 109
14 Bottom	mean	8.3	10.0	85
	range	1.5 - 16.3	7.4 - 12.7	65 - 105
16 Top	mean	10.9	10.8	98
	range	1.9 - 17.9	8.8 - 12.6	76 - 112
16 Bottom	mean	10.3	10.6	94
	range	1.9 - 16.6	8.6 - 12.4	74 - 115
20 Mid	mean	10.7	10.6	99
	range	1.7 - 17.0	8.1 - 12.8	80 - 115
23 Top	mean	10.5	10.8	96
	range	1.5 - 18.4	8.2 - 12.7	69 - 110
23 Mid	mean	9.7	10.7	93
	range	1.4 - 16.4	8.2 - 12.7	69 - 116
23 Bottom	mean	8.4	10.3	87
	range	1.4 - 15.4	7.3 - 12.7	67 - 115
24 Top	mean	11.1	10.8	98
	range	1.5 - 18.3	9.4 - 12.7	84 - 111
24 Mid	mean	9.8	10.4	91
	range	1.3 - 17.1	8.1 - 12.8	80 - 110
24 Bottom	mean	8.2	9.9	83
	range	1.3 - 15.4	6.9 - 12.8	63 - 107

in previous years (Table 2.6 and 2.7). Monthly temperature data, including temperature profiles are presented in Appendix 2. Little temperature stratification could be detected at Location 11 for the months of April, June and August (Figure 2.1). Throughout the 1973 study, locations along the 10-ft contour exhibited little or no thermal stratification. At Location 12, along the 20-ft contour (Figure 2.2), waters were stratified in June and August. During April, large waves created turbulence which thoroughly mixed the shallower water and inhibited thermal stratification. During June and August, however, thermoclines existed from a depth of 2 to 5 m where the rate of change in temperature with respect to depth was greatest. An analogous situation existed at Location 13 along the 30-ft contour (Figure 2.3). Thermoclines at the deeper locations extended from a depth of 4 to 7 m. At location 14 (along the 40-ft contour) a thermocline from 4 to 10 m in depth was present in June and August (Figure 2.4). The temperature distributions shown in these graphs and the accumulated profile data indicate that the thermocline which existed during August covered a much greater temperature range than during June, indicating a greater degree of stratification. Thermoclines were present during June, August, September and October. In other months no significant thermal stratification was evident in the study area. An analysis of 1972 temperature data lead to the conclusion that thermoclines in the study area were metastable because of their destruction by rough lake conditions during the few days between sampling. Monitoring during 1973 supports this conclusion. Temperatures were generally higher at locations

Table 2.6. Yearly means and ranges for data obtained during 1972 from Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant.[a]

Parameter		2 Mid	7 Top	7 Bot	11 Mid	12 Top	12 Bot
Temperature (°C)	Mean	10.2	10.5	8.9	10.4	10.1	9.0
	Range	6.1-13.1	6.3-14.1	6.2-11.6	6.2-13.6	6.2-12.5	6.2-11.4
D.O. (mg/l)	Mean	11.7	11.8	12.1	11.5	11.5	11.5
	Range	10.5-13.5	11.0-12.3	11.0-12.7	10.4-12.5	10.4-12.8	10.5-12.4
Oxygen saturation (%)	Mean	104	105	104	102	102	99
	Range	93-125	96-113	96-112	96-116	96-119	86-110
pH	Mean	8.2	8.2	8.2	8.2	8.1	8.2
	Range	8.1-8.5	8.1-8.4	8.1-8.4	7.7-8.5	7.5-8.5	8.0-8.5
Alkalinity, total (mg/l-$CaCO_3$)	Mean	113	113	110	116	114	116
	Range	104-122	107-118	97-117	107-125	105-120	107-126
Alkalinity, phenolphthalein (mg/l-$CaCO_3$)	Mean	1	0	0	1	1	0
	Range	0-4	0-2	0-2	0-4	0-3	0-3
Hardness, total (mg/l-$CaCO_3$)	Mean	144	135	129	140	134	137
	Range	112-183	127-152	122-151	122-161	124-153	125-151
Chloride (mg/l)	Mean	7.3	7.4	7.4	7.4	7.4	7.3
	Range	6.5-8.0	6.8-8.0	6.8-8.5	6.8-8.0	6.5-8.0	6.5-8.0
Fluoride (mg/l)	Mean	0.11	0.10	0.10	0.10	0.10	0.11
	Range	0.04-0.15	0.05-0.14	0.05-0.15	0.05-0.15	0.05-0.17	0.05-0.17
Sulfate (mg/l)	Mean	19.1	19.2	18.4	18.8	18.5	18.8
	Range	17.2-22.2	17.5-2 .0	16.0-19.5	17.2-20.5	17.0-20.5	17.0-20.1
Sodium (mg/l)	Mean	4.3	4.2	4.3	4.3	4.3	4.3
	Range	3.8-4.7	3.7-4.7	3.7-5.3	3.8-4.7	3.7-4.6	3.8-4.7
Potassium (mg/l)	Mean	1.7	1.4	1.3	1.6	1.4	1.4
	Range	1.2-2.7	1.1-1.8	1.0-1.8	1.1-2.5	1.1-1.9	1.1-2.0
Conductance, specific (µmhos/cm)	Mean	258	256	257	256	254	255
	Range	238-277	237-280	235-284	238-272	238-264	239-264
Residue, filtrable (total dissolved solids)	Mean	179	177	174	158	159	158
	Range	144-306	146-298	150-276	146-174	142-176	146-178
Turbidity (J.T.U.)	Mean	28	11	11	24	10	13
	Range	<1-110	<1-29	<1-29	<1-87	<1-28	<1-37
Orthophosphate, soluble (mg/l-P)	Mean	0.016	0.005	0.007	0.003	0.002	0.020
	Range	<0.001-0.059	<0.001-0.027	<0.001-0.033	<0.001-0.005	<0.001-0.004	<0.001-0.29
Phosphorus, total (mg/l-P)	Mean	0.051	0.023	0.024	0.040	0.024	0.040
	Range	0.008-0.15	0.005-0.059	0.007-0.055	0.008-0.10	0.005-0.063	0.010-0.29
Ammonia (mg/l-N)	Mean	0.03	0.03	0.03	0.02	0.04	0.03
	Range	<0.01-0.07	<0.01-0.08	<0.01-0.09	<0.01-0.06	<0.01-0.16	<0.01-0.11
Nitrate (mg/l-N)	Mean	0.23	0.24	0.22	0.23	0.22	0.26
	Range	0.06-0.41	0.09-0.49	0.09-0.31	0.09-0.43	0.08-0.43	0.09-0.79
Nitrite (mg/l-N)	Mean	0.0035	0.0031	0.0025	0.0028	0.0028	0.0031
	Range	0.0018-0.0074	0.0015-0.0075	0.0017-0.0036	0.0013-0.0057	0.0014-0.0042	0.0014-0.0052
Organic nitrogen, total (mg/l-N)	Mean	0.25	0.20	0.23	0.23	0.21	0.23
	Range	0.04-0.55	0.04-0.41	0.03-0.51	0.04-0.47	0.05-0.46	0.07-0.49

Table 2.6. Continued.

Parameter		14 Top	14 Mid	14 Bot	16 Top	16 Bot	20 Mid
Temperature (°C)	Mean	9.9	8.3	7.5	10.7	9.1	11.0
	Range	6.4-13.2	5.4-12.0	5.4-11.7	6.2-14.1	6.2-11.4	6.4-14.0
D.C. (mg/l)	Mean	11.7	12.1	12.0	11.4	11.8	11.0
	Range	10.5-12.5	10.9-12.9	10.8-13.1	10.6-12.0	10.4-12.7	9.8-11.8
Oxygen saturation (%)	Mean	102	102	100	102	101	99
	Range	96-111	96-111	89-107	95-109	92-109	90-109
pH	Mean	8.2	8.2	8.1	8.3	8.2	8.3
	Range	8.0-8.5	7.9-8.3	8.0-8.3	8.1-8.6	8.0-8.6	8.1-8.6
Alkalinity, total (mg/l-$CaCO_3$)	Mean	110	112	110	116	119	118
	Range	104-119	105-122	105-116	105-128	106-128	106-137
Alkalinity, phenolphthalein (mg/l-$CaCO_3$)	Mean	0	All	All	1	1	1
	Range	0-2	Zero	Zero	0-6	0-6	0-7
Hardness, total (mg/l-$CaCO_3$)	Mean	133	132	134	140	143	146
	Range	125-144	124-145	127-156	125-161	122-174	124-183
Chloride (mg/l)	Mean	7.4	7.4	7.3	7.6	7.5	7.8
	Range	7.0-8.0	6.8-8.5	6.0-8.0	7.0-9.0	6.8-9.5	6.8-10.5
Fluoride (mg/l)	Mean	0.10	0.10	0.10	0.10	0.10	0.10
	Range	0.05-0.15	0.04-0.15	0.05-0.16	0.05-0.15	0.05-0.15	0.05-0.16
Sulfate (mg/l)	Mean	18.2	18.8	18.3	19.3	19.7	18.5
	Range	17.2-19.2	17.5-22.5	17.7-19.5	17.5-24.2	17.3-24.8	17.2-20.0
Sodium (mg/l)	Mean	4.2	4.2	4.3	4.3	4.3	4.5
	Range	3.8-4.6	3.8-4.6	3.8-4.7	3.8-5.2	3.8-5.3	3.8-5.8
Potassium (mg/l)	Mean	1.3	1.3	1.4	1.5	1.6	2.0
	Range	1.1-1.5	1.1-1.6	1.1-2.1	1.2-2.1	1.1-2.6	1.2-3.4
Conductance, specific (µmhos/cm)	Mean	254	254	256	259	260	264
	Range	238-264	239-266	238-271	238-282	239-294	238-316
Residue, filtrable (total dissolved solids) (mg/l)	Mean	158	160	160	164	161	165
	Range	142-170	138-174	150-174	147-194	140-196	144-204
Turbidity (J.T.U.)	Mean	4	4	6	17	18	32
	Range	<1-16	<1-20	<1-33	<1-43	<1-43	<1-96
Orthophosphate, soluble (mg/l-P)	Mean	0.002	0.002	0.003	0.005	0.005	0.008
	Range	0.001-0.005	<0.001-0.005	0.001-0.009	<0.001-0.019	<0.001-0.020	<0.001-0.042
Phosphorus, total (mg/l-P)	Mean	0.012	0.012	0.016	0.030	0.030	0.045
	Range	0.005-0.026	0.006-0.032	0.006-0.031	0.004-0.070	0.009-0.079	0.008-0.11
Ammonia (mg/l-N)	Mean	0.02	0.01	0.02	0.02	0.02	0.02
	Range	<0.01-0.04	<0.01-0.02	<0.01-0.06	<0.01-0.04	<0.01-0.08	<0.01-0.06
Nitrate (mg/l-N)	Mean	0.21	0.22	0.22	0.21	0.22	0.23
	Range	0.13-0.28	0.16-0.29	0.15-0.36	0.12-0.30	0.10-0.37	0.08-0.39
Nitrite (mg/l-N)	Mean	0.0030	0.0026	0.0027	0.0029	0.0027	0.0030
	Range	0.0013-0.0050	0.0010-0.0040	0.0010-0.0038	0.0012-0.0068	0.0009-0.0053	0.0015-0.0052
Organic nitrogen, total (mg/l-N)	Mean	0.18	0.16	0.18	0.20	0.20	0.21
	Range	0.04-0.27	0.04-0.29	0.04-0.30	0.04-0.37	0.07-0.48	0.02-0.45

Table 2.6. Continued.

Parameter		14 Top	14 Mid	14 Bot	16 Top	16 Bot	20 Mid
Silica, soluble	Mean	0.82	0.82	0.87	0.84	0.90	0.94
(mg/l-SiO_2)	Range	0.59-1.1	0.59-1.1	0.60-1.3	0.45-1.8	0.44-2.0	0.40-2.6
Bacteria, standard plate count at 20 C	Mean[b]	16000	22000	23000	67000	35000	140000
(No./100 ml)	Range	<130-750000	<130-750000	<130-630000	1600-930000	1000-820000	2500-4200000
Bacteria, standard plate count at 35 C	Mean[b]	32000	43000	36000	83000	69000	160000
(No./100 ml)	Range	2300-800000	1400-780000	1100-480000	2900-4000000	1500-2200000	3000-4300000
Bacteria, fecal coliform	Mean[b]	1	1	1	3	3	12
(No./100 ml)	Range[c]	0-36	0-4	0-7	0-36	0-23	0-440
Bacteria, fecal streptococci	Mean[b]	34	22	40	32	59	47
(No./100 ml)	Range[c]	2-450	0-470	2-290	0-430	7-330	1-510
Biochemical oxygen demand (5 day)	Mean	2.3	2.4	2.4	2.5	2.8	2.7
(mg/l)	Range	0.8-3.7	1.1-4.1	1.0-4.1	1.7-3.7	0.9-6.2	1.1-3.8
Chemical oxygen demand	Mean	6.7	6.1	7.2	6.8	7.1	7.5
(mg/l)	Range	3.2-9.0	2.2-8.6	4.5-12	1.6-11	2.8-13	1.3-17
Organic carbon, total	Mean	5	5	5	7	6	6
(mg/l)	Range	2-11	1-13	2-11	3-14	2-11	2-12
Color, true	Mean	2	2	2	3	3	4
(units)	Range	1-3	1-2	1-4	1-8	1-9	1-14
Iron	Mean	0.055	0.059	0.084	0.29	0.31	0.67
(mg/l)	Range	0.009-0.26	0.010-0.27	0.013-0.43	0.017-0.93	0.019-1.3	0.011-2.2
Manganese	Mean	1	1	2	3	3	5
(µg/l)	Range	<1-2	<1-3	<1-4	<1-10	<1-18	<1-15
Mercury	Mean	0.29	0.46	0.38	0.17	0.37	0.18
(µg/l)	Range	<0.05-1.1	<0.05-4.5	<0.05-2.7	<0.05-19	0.05-1.1	<0.05-0.72
Lead	Mean	4	4	2	3	3	3
(µg/l)	Range	<1-9	<1-11	<1-6	1-8	1-5	<1-7
Copper	Mean	2.2	2.5	2.7	3.6	3.1	4.7
(µg/l)	Range	0.9-4.7	0.8-6.0	0.8-6.0	1.8-8.3	1.6-4.5	2.6-8.0
Zinc	Mean	14	8	9	12	11	13
(µg/l)	Range	1-56	<1-26	<1-22	<1-62	<1-35	<1-28
Chromium, total	Mean	1	2	1	1	1	1
(µg/l)	Range	<1-3	<1-6	<1-3	<1-2	<1-3	<1-2
Cadmium	Mean	0.3	0.1	0.2	0.2	0.2	0.3
(µg/l)	Range	<0.1-0.9	<0.1-0.3	<0.1-0.4	<0.1-0.3	<0.1-0.4	<0.1-1.2
Nickel	Mean	2	2	2	2	2	2
(µg/l)	Range	<1-4	<1-4	<1-3	<1-4	<1-4	<1-4
Arsenic	Mean	1	1	1	1	1	1
(µg/l)	Range	<1-1	<1-1	<1-1	<1-2	<1-2	<1-2
Boron	Mean	0.04	0.05	0.05	0.06	0.05	0.04
(mg/l)	Range	<0.01-0.09	0.01-0.09	0.01-0.15	0.01-0.13	0.02-0.10	<0.01-0.13

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[a] Industrial BIO-TEST Laboratories, Inc. 1973

[b] Bacteria data means are expressed as geometric mean defined as $\sqrt[n]{(a_1)(a_2)(a_3)\ldots(a_n)}$

[c] The integer one (1) was substituted for zero (0) to prevent the product under the square root sign from vanishing.

Table 2.7. Yearly means and ranges for data obtained during 1971 from Lake Michigan along a transect directly in front of the Kewaunee Nuclear Power Plant.[a]

Parameter		5 Ft. Depth (Mid)	25 Ft. Depth (Top)	25 Ft. Depth (Bottom)
Temperature	Mean	11.0	10.1	9.8
(°C)	Range	5.7-17.6	5.2-17.2	5.2-16.8
Oxygen, Dissolved	Mean	10.9	10.0	10.1
(mg/l)	Range	8.0-13.0	7.8-12.8	7.4-13.0
Oxygen Saturation	Mean	97	87	86
(%)	Range	83-104	79-102	76-102
Biochemical Oxygen	Mean	2.3	2.0	1.8
Demand (mg/l)	Range	0.5-5.3	0.9-4.6	0.3-5.0
Chemical Oxygen	Mean	8.6	11	5.5
Demand (mg/l)	Range	4.5-12	1.2-27	2.4-8.7
Total Organic Carbon	Mean	4	3	3
(mg/l)	Range	3-4	1-5	2-4
Nitrate as N	Mean	0.14	0.23	0.19
(mg/l)	Range	0.10-0.24	0.17-0.56	0.10-0.43
Phosphorus, Total	Mean	0.049	0.014	0.015
(mg/l)	Range	0.039-0.072	0.004-0.029	0.006-0.026
Orthophosphate as P	Mean	0.003	0.001	0.001
(mg/l)	Range	0.001-0.007	<0.001-0.003	<0.001-0.002
Alkalinity, Total	Mean	110	107	107
(mg/l)	Range	97-122	98-114	100-111
pH (units)	Mean	7.9	7.9	7.9
	Range	7.7-8.2	7.4-8.4	7.4-8.3
Fecal Coliform	Mean	1	1	1
Bacteria (No/100 ml)	Range	0-4	0-4	0-4

Table 2.7. Continued.

		5 Ft. Depth (Mid)	25 Ft. Depth (Top)	25 Ft. Depth (Bottom)
Fecal Streptococci	Mean	50	5	20
Bacteria (No/100 ml)	Range	0-140	0-27	0-94
Conductance,	Mean	267	268	267
Specific (µmhos/cm)	Range	261-270	260-276	260-275
Chloride	Mean	7.1	7.2	7.2
(mg/l)	Range	6.5-8.3	6.5-8.5	6.8-8.5
Turbidity	Mean	51	8	8
(J.T.U.)	Range	36-84	3-18	1-18
Silica	Mean	0.91	1.1	1.1
(mg/l)	Range	0.40-1.4	0.64-1.4	0.71-1.4
Iron	Mean	0.70	0.13	0.19
(mg/l)	Range	0.58-0.80	0.006-0.28	0.12-0.27
Chromium	Mean	0.002	0.004	0.002
(mg/l)	Range	0.001-0.004	<0.001-0.019	<0.001-0.009

[a] Industrial BIO-TEST Laboratories, Inc. 1972.

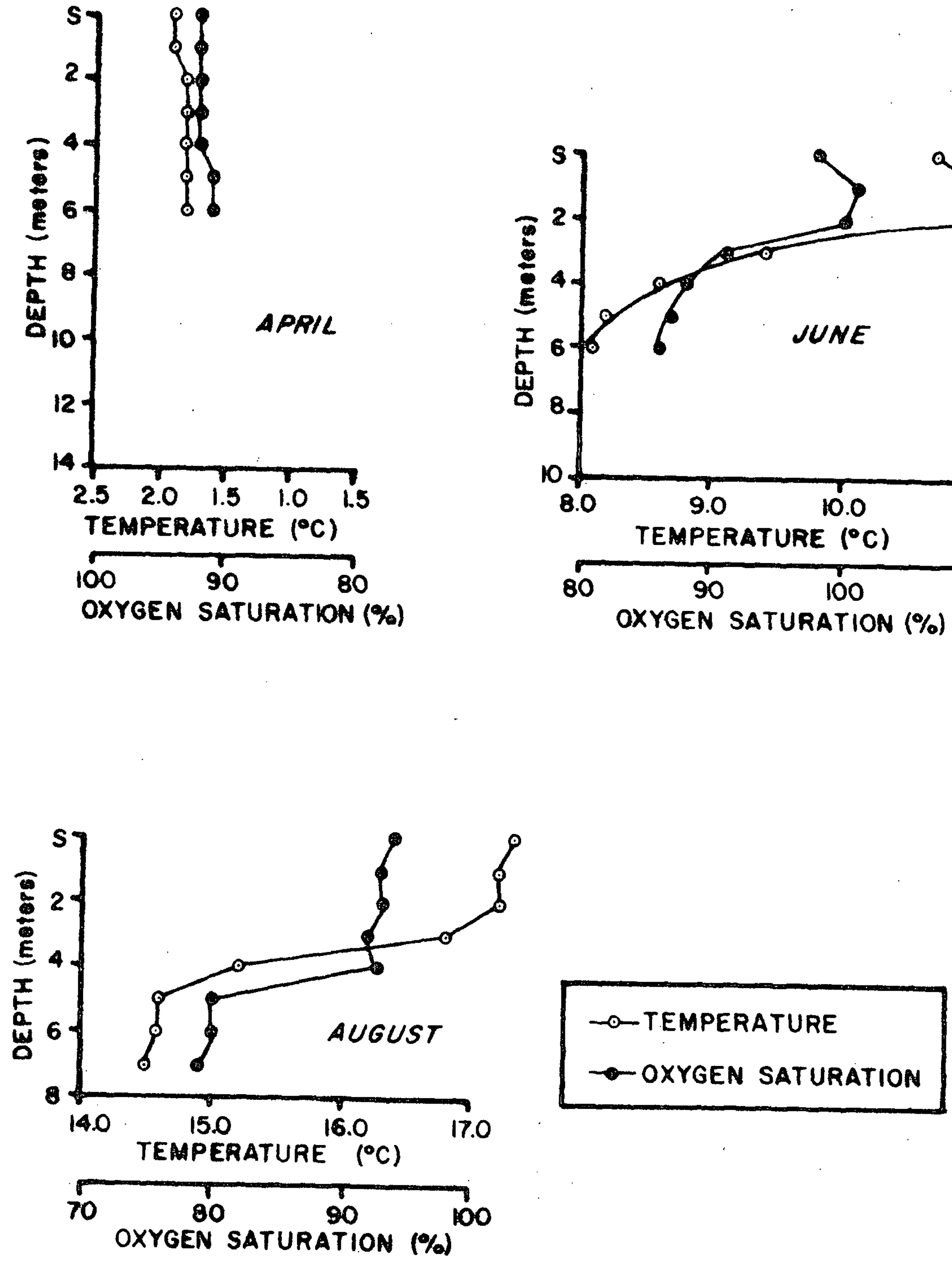

Figure 2.2. Temperature vs. depth measurements taken at Location 12 in the vicinity of the Kewaunee Nuclear Power Plant during 1973.

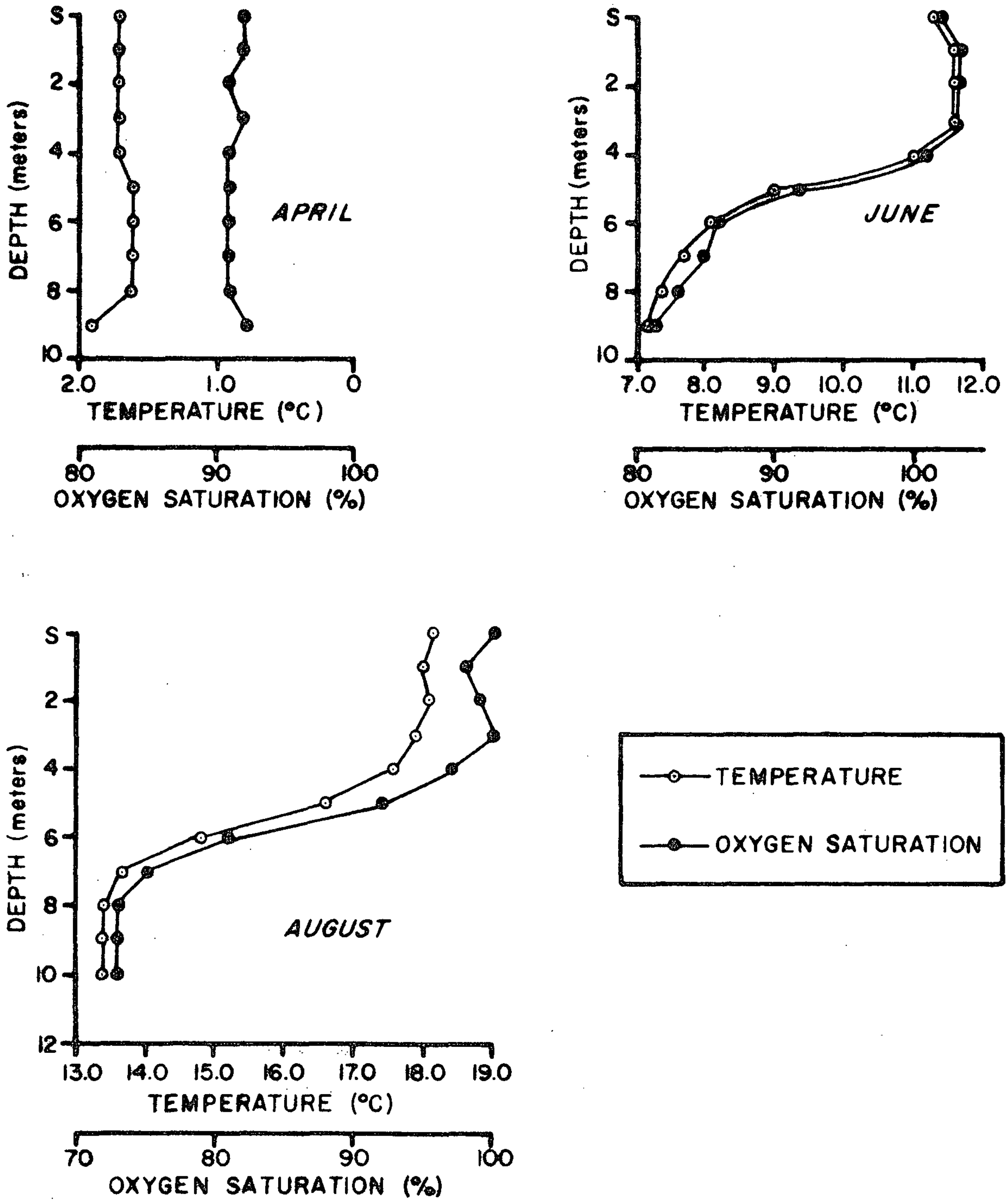

Figure 2.3. Temperature vs. depth measurements taken at Location 13 in the vicinity of the Kewaunee Nuclear Power Plant during 1973.

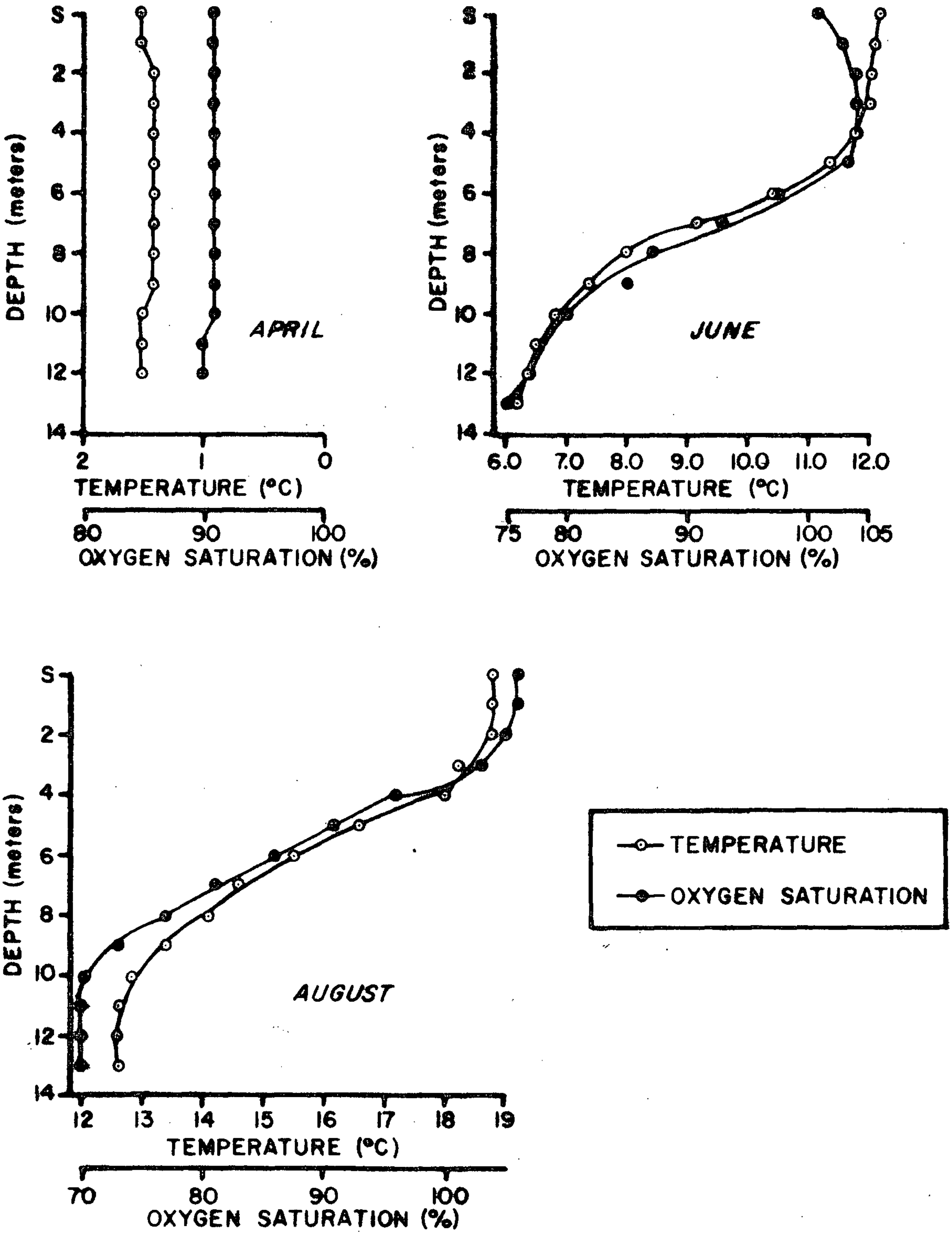

Figure 2.4. Temperature vs. depth measurements taken at Location 14 in the vicinity of the Kewaunee Nuclear Power Plant during 1973.

along Transect I than at those along Transect V, and this difference may be due to a number of factors, the more important of which may be shoreline configuration and bottom contours as they affect water movement.

Values for dissolved oxygen (D. O.) followed an opposite seasonal trend compared to temperature, exhibiting the highest values during April and November and lower values during the summer months. This trend is anticipated due to the lower solubility of oxygen in warmer waters. D. O. values during the study ranged from 6.9 to 13.2 mg/l (Table 2.5). The D. O. values in the study area were more than adequate for the support of aquatic life (Federal Water Pollution Control Administration 1968). Dissolved oxygen values were lower for bottom samples with the exception of September's profile data. Differences between surface and bottom measurements were as much as 2.5 mg/l. This phenomena may be due to natural oxygen consuming processes at the lake bottom, especially since bottom samples often had higher biochemical oxygen demand (B. O. D.) values than surface samples.

The existence of a thermocline has an important effect on the distribution of dissolved oxygen since a thermocline can act as a natural barrier for exchange of gases and other constituents between the hypolimnion and epilimnion (Hutchinson 1967). Oxygen saturation values closely paralleled the temperature distribution with higher values near the top of the water column than the bottom. When no thermocline existed, there was little change in oxygen saturation and D. O. values from top to bottom. Average D. O. values were slightly below 1972 values for the same locations (Industrial BIO-TEST

Laboratories, Inc. 1973).

No apparent seasonal trends for oxygen saturation were evident. The values were largely a function of water temperature and turbulence. Average values for 1973 were somewhat below those of 1972 (Table 2.6) at the same locations, but comparable to data from 1971 (Table 2.7).

D. Nutrients

The nutrients analyzed during this study included soluble orthophosphate, total phosphorus, soluble silica, nitrate, nitrite, ammonia and total organic nitrogen.

Soluble orthophosphate concentrations were uniform throughout the study (Table 2.8). Values observed in 1973 were considerably lower than those in 1972 (Table 2.6), but comparable with other data from the area (Tables 2.7 and 2.9). There were no apparent spatial distributions or seasonal trends.

Total phosphorus levels displayed a wide variability, ranging from 0.002 to 0.063 mg/l (Table 2.8). Total phosphorus levels decreased with increasing distance from shore, and increased with increasing depth. Higher values were associated with turbid water caused by wave activity and bottom scouring. Total phosphorus and several other parameters affected by weather conditions exhibited similar fluctuations (Figure 2.5). The fluctuations were not as consistent among the other parameters nor as great at the deeper offshore locations, but differences were still present (Figure 2.6). Further evidence for the influence of weather on values for total phosphorus and other parameters is

Table 2.8. Yearly means and ranges for total phosphorus, soluble orthophosphate and soluble silica values in samples collected from Lake Michigan near the Kewaunee Nuclear Power Plant in 1973.

Location		Total Phosphorus (mg/l)	Ortho-Phosphate (mg/l-P)	Soluble Silica (mg/l-SiO₂)
2 Mid	mean	0.021	0.001	0.49
	range	0.004 - 0.063	<0.001 - 0.001	0.11 - 1.1
7 Top	mean	0.016	0.001	0.46
	range	0.008 - 0.032	<0.001 - 0.002	0.16 - 1.0
7 Bottom	mean	0.018	0.001	0.46
	range	0.009 - 0.037	<0.001 - 0.003	0.15 - 1.0
11 Mid	mean	0.020	0.001	0.46
	range	0.008 - 0.039	<0.001 - 0.001	0.15 - 1.1
12 Top	mean	0.012	0.001	0.47
	range	0.003 - 0.020	<0.001 - 0.002	0.17 - 0.97
12 Bottom	mean	0.015	0.001	0.50
	range	0.003 - 0.043	<0.001 - 0.002	0.20 - 1.0
14 Top	mean	0.008	0.001	0.50
	range	0.002 - 0.015	<0.001 - 0.001	0.11 - 1.1
14 Mid	mean	0.008	0.001	0.45
	range	0.005 - 0.012	<0.001 - 0.002	0.14 - 0.98
14 Bottom	mean	0.011	0.001	0.61
	range	0.002 - 0.029	<0.001 - 0.003	0.14 - 1.3
16 Top	mean	0.014	0.001	0.47
	range	0.004 - 0.042	<0.001 - 0.001	0.17 - 1.1
16 Bottom	mean	0.019	0.001	0.48
	range	0.007 - 0.053	<0.001 - 0.002	0.16 - 1.1
20 Mid	mean	0.021	0.001	0.53
	range	0.008 - 0.052	<0.001 - 0.004	0.15 - 1.2
23 Top	mean	0.007	0.001	0.57
	range	0.005 - 0.015	<0.001 - 0.004	0.15 - 1.2
23 Mid	mean	0.009	0.001	0.60
	range	0.002 - 0.018	<0.001 - 0.002	0.15 - 1.3
23 Bottom	mean	0.010	0.001	0.68
	range	0.003 - 0.019	<0.001 - 0.001	0.16 - 1.4
24 Top	mean	0.009	0.001	0.49
	range	0.004 - 0.017	<0.001 - 0.002	0.15 - 1.0
24 Mid	mean	0.009	0.001	0.48
	range	0.003 - 0.019	<0.001 - 0.003	0.14 - 1.0
24 Bottom	mean	0.009	0.001	0.61
	range	0.002 - 0.018	<0.001 - 0.003	0.16 - 1.4

Table 2.9. Water quality data collected at Point Beach Nuclear Power Plant, June-September 1971.[a]

Station	Depth, ft	Temperature, (°C)				Total Alkalinity, (mg/l)				NO_3-N (mg/l)				NO_2-N (µg/l)				Ortho PO_4 as P (µg/l)			
		June	July	Aug	Sep	June	July	Aug	Sep	June	July	Aug	Sep	June	July	Aug	Sep	June	July	Aug	Sep
Discharge	Surface	21.0	16.5				110			0.15	0.24			2	2			4	<1		
	6	21.5								0.15				2.2				4			
	12	21.0								0.15				1.5				2			
3	Surface	12.0	9.0	17.0	11.8		111	109	112	0.15	0.25	0.12	0.26	1.5	3.2	2.2	0.6	2	<1	1	<1
	8	11.0	8.0				110			0.15	0.24			1.5	2.4			1	<1		
	16	10.5	7.0	17.0	10.0		111	109	112	0.14	0.25	0.12	0.25	1.8	2.0	2.2	0.7	3	1	<1	<1
4	Surface	15.5	16.0	21.0			111	109		0.14	0.16	0.14		1.6	2.3	1.8		2	<1	2	
	8	11.0	11.5				111			0.14	0.18			1.7	2.0			2	<1		
	16	10.5	11.0	17.0			110	109		0.14	0.17	0.13		1.7	2.0	1.7		1	<1	1	
5	Surface	14.5	14.0	18.0	11.0		112	108	113	0.17	0.13	0.12	0.25	2.1	1.5	1.8	1.0	3	3		<1
	8	13.0	12.5				111			0.15	0.14				1.7			1	<1		
	16	12.0	12.0	16.5	10.0		112	108	112	0.17	0.14	0.12	0.25	1.7	2.1	1.8	0.8	2	<1	1	<1
16	Surface	13.5	11.5	18.0	10.5		110	109	111	0.16	0.18	0.12	0.23	1.7	2.0	1.7	0.7	1	<1	<1	<1
	15	10.5	11.0				112			0.16	0.19			1.6	2.1			1	<1		
	30	10.0	10.5	16.5	8.8		111	110	112	0.16	0.20	0.14	0.25	1.6	1.7	1.6	0.5	1	<1	<1	<1
7	Surface	12.5			10.0				114	0.15			0.26	1.7			0.5	1			<1
	8	12.0								0.18				1.8				1			
	16	12.5			10.2				114	0.14			0.25	1.7			0.6	1			<1
1	Surface	13.5	9.0	17.0	11.8		112	113	113	0.16	0.26	0.14	0.29	1.9	2.3	0.17	0.8	5	1	<1	26
	8	12.0	8.0	17.0	10.5		110			0.20	0.25			1.8	2.1			2	<1		
	16	10.5	7.0	17.0	10.0		111	108	111	0.17	0.25	0.14	0.21		2.1	0.17	0.5	2	2	<1	<1
14	Surface	13.0	8.0	16.5	10.5		111	109	112	0.17	0.25	0.15	0.22	1.9	2.1	0.18	0.6	1	2	<1	<1
	15	10.0	7.0	16.5	10.0		110			0.18	0.25			1.8	2.1			2	<1		
	30	9.0	6.5	16.5	8.0		111	109	112	0.18	0.25	0.13	0.26	1.4	2.8	0.16	0.3	1	<1	<1	<1
19	Surface	13.0	12.5		11.8		110		113	0.17	0.23		0.24	1.8	1.8		0.8	1	<1		<1
	16	10.5	11.5				110			0.17	0.18			1.5	1.6			1	2		
	30																				
21	Surface	12.5	12.5	17.0			112	110		0.16	0.15	0.11		1.9	1.6	1.9		2	<1	3	
	8	12.0	12.0				111			0.17	0.15				1.2			2	<1		
	16	12.2	11.5	17.0			110	109		0.16	0.15	0.12		1.9	1.4	1.7		2	<1	1	
23	Surface	14.0	12.5	17.0	11.8		110	110	112	0.17	0.16	0.12	0.25	2.0	2.3	1.7	0.9	1	<1	1	<1
	18	11.0	12.5				110			0.18	0.18			2.0	2.1			2	<1		
	36	11.0	10.5	16.5	8.8		110	110	112	0.17	0.16		0.28	1.6	2.0	1.6	0.6	1	<1	1	<1
Intake										0.15				1.5				2			

Table 2.9. Continued

Station	Depth, ft	SiO2 (mg/l) June	SiO2 (mg/l) July	SiO2 (mg/l) Aug	SiO2 (mg/l) Sep	pH (units) June	pH (units) July	pH (units) Aug	pH (units) Sep	D.O. (mg/l) June	D.O. (mg/l) July	D.O. (mg/l) Aug	D.O. (mg/l) Sep	Specific Conductance, (µmho/cm) June	Specific Conductance, (µmho/cm) July	Specific Conductance, (µmho/cm) Aug	Specific Conductance, (µmho/cm) Sep
Discharge	Surface	1.4	1.2			8.0	8.0		8.3	9.6	11.8			260	260		
	6	0.72				8.0				9.5				260			
	12	0.72				8.0				9.4				255			
3	Surface	0.71	1.2	0.45	1.1	8.5	8.5		8.5	10.2	12.6		10.8	250	260	225	260
	8	0.72	1.1			8.5	8.3			10.4	12.4		10.8	250	255	220	260
	16	0.72	1.2	0.39	1.1	8.5	8.3			10.2	12.8		10.8	250	260	220	260
4	Surface	0.71	0.71	0.43		8.3	8.4			9.6	12.4			250	260	230	
	8	0.72	0.72			8.6	8.5			10.2	13.0			250	255	230	
	16	0.72	0.75	0.41		8.5	8.5			10.4	13.1			250	260	230	
5	Surface	0.68	0.81	0.43	1.1	8.5	8.5			10.0	12.8		10.8	250	260	220	260
	8	0.68	0.71			8.5	8.5			10.2	13.0		10.8	250	260	220	260
	16	0.66	0.75	0.41	1.1	8.5	8.5			10.4	13.0		10.8	250	260	225	260
16	Surface	0.68	0.75	0.41	1.2	8.5	8.5			10.3	12.6		10.8	260	260	210	260
	15	0.71	0.83			8.5	8.5			10.6	12.8		10.8	250	260	210	260
	30	0.72	0.77	0.47	1.2	8.5	8.5			10.6	13.2		10.8	260	260	210	260
7	Surface	0.68			1.1	8.5				10.2			10.8	250			260
	8	0.68				8.5				10.2			10.8	260			260
	16	0.68			1.2	8.5				10.2			11.0	255			260
1	Surface	0.68	1.2	0.41	1.3	8.5	8.2			10.0	12.6		11.4	260	255	210	255
	8	0.81	1.2			8.5	8.2			10.2	12.6		11.0	250	260	210	265
	16	0.66	1.2	0.43	1.2	8.5	8.3			10.4	12.6		10.8	260	260	210	255
14	Surface	0.68	1.3	0.45	1.2	8.5	8.3		8.5	10.0	12.4		11.0	260	260	210	260
	15	0.75	1.3			8.5	8.3			10.6	12.6		11.0	260	260	210	260
	30	0.81	1.3	0.43	1.3	8.5	8.3			10.6	12.6		11.0	250	260	210	260
19	Surface	0.66	0.71		1.0	8.4	8.5			10.0	12.0		10.4	250	260		260
	16	0.75	0.71			8.5	8.5			10.4	13.0		10.7	250	260		260
	30	0.72	0.66		1.2	8.5	8.5			10.4	13.4		10.8	255	260		260
21	Surface	0.68	0.68	0.41		8.5	8.5		8.4	10.0	13.0		10.7	250	260	200	260
	8	0.71	0.68			8.5	8.5			10.0	12.9		10.8	250	260	200	260
	16	0.71	0.68	0.41		8.5	8.5			10.0	13.0		11.0	260	260	200	260
23	Surface	0.71	0.66	0.39	1.0	8.5	8.5			10.4	12.5		10.9	255	260	210	260
	18	0.68	0.68			8.6	8.5			10.4	12.4		10.8	255	260	210	260
	36	0.75	0.66	0.41	1.2	8.6	8.5			10.4	13.0		11.0	255	260	210	260
Intake		0.72				8.3											

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[a] Weschler, M. D., S. A. Spigarelli, and D. N. Edgington. 1971. The measurement of major nutrients and water quality parameters at Point Beach - 1971. Argonne National Laboratory, ANL-7860. Argonne, Illinois.

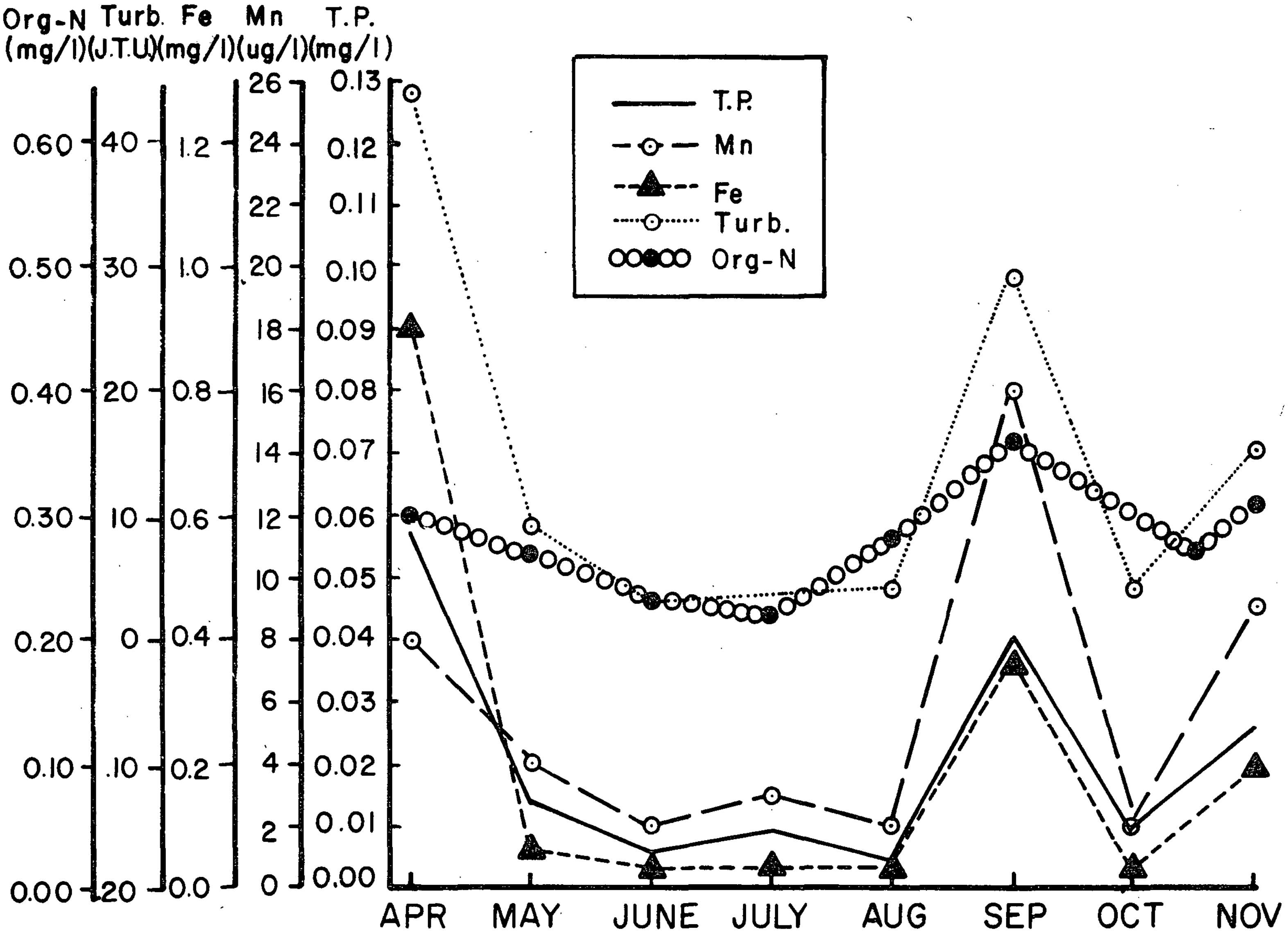

Figure 2.5 - Seasonal distribution of organic nitrogen (Org-N), turbidity (Turb.), iron (Fe), manganese (Mn) and total phosphorus (T.P.) at inshore Location 2 MID.

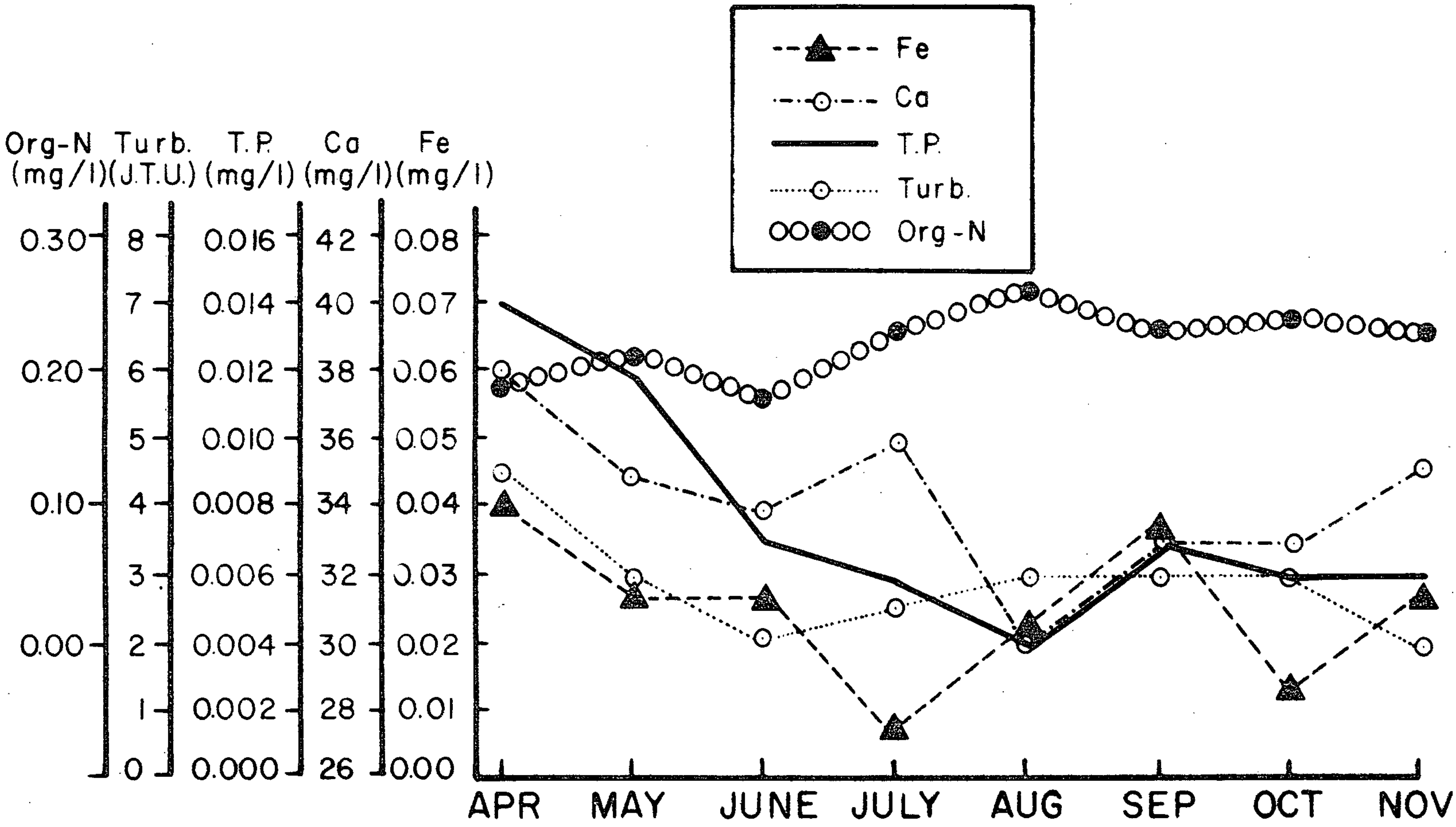

Figure 2.6 - Seasonal distribution of organic nitrogen (Org-N), turbidity (Turb.), total phosphorus (T.P.), calcium (Ca) and iron (Fe) at the offshore Location 14 TOP.

apparent from the data shown in Table 2.10. The high concentrations of metals, nitrogen, and phosphorus in sediments contributed substantially to the abundance of these constituents in the water during turbulent periods as will be discussed in subsequent sections. Total phosphorus levels were higher in the spring and fall when wave activity was more intense. No correlation between total phosphorus and orthophosphate or any other nutrient measured was evident. Values for total phosphorus in 1973 were about half those measured in 1972.

Soluble silica values ranged from 0.11 to 1.4 mg/l-SiO_2 during this study (Table 2.8). From September to November soluble silica values decreased gradually from south to north of the Plant. During June and November silica values were higher for offshore locations than inshore locations. During July and August the opposite trend was observed. Silica values were higher for top samples than bottom samples for the month of May, but during June, August, September and October silica values were substantially higher for bottom samples when significant thermal stratification occurred. A similar trend was apparent in August 1972. Lowest silica values were observed in early summer months (Figures 2.7 and 2.8). Phytoplankton populations were highest in April, lowest in July and increased moderately in September. No correlation between silica concentrations and phytoplankton populations (including diatoms) is apparent from these data (Chapter 3). The silica values decreased in November, after reaching a maximum in October. Silica values in 1973 were notably lower than those measured in 1971 and 1972 at the same locations.

Table2.10 Average chemical compositions[a] of Lake Michigan sediments.

Parameter	South[b] Basin	Middle[b] Basin	Northern[b] Basin	Southwestern[c] Basin
Calcium	59500	40700	57200	63000
Magnesium	23200	17600	11500	42000
Iron	18000	18800	17700	4080
Manganese	720	1000	1400	192
Copper	-	-	-	4.3
Potassium	-	-	-	144
Total Nitrogen	2040	1830	2370	-
Total Phosphorus	-	-	-	257

[a] Parts per million based on dry weight of sediment.

[b] Callender, E. 1969. Geochemical characteristics of Lakes Michigan and Superior sediments. Proc. 12th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res., p. 124-160.

[c] Industrial BIO-TEST Laboratories, Inc., 1973. Evaluation of thermal effects in southwestern Lake Michigan (April 1971-March 1972). Report to Commonwealth Edison Company, Chicago, Illinois.

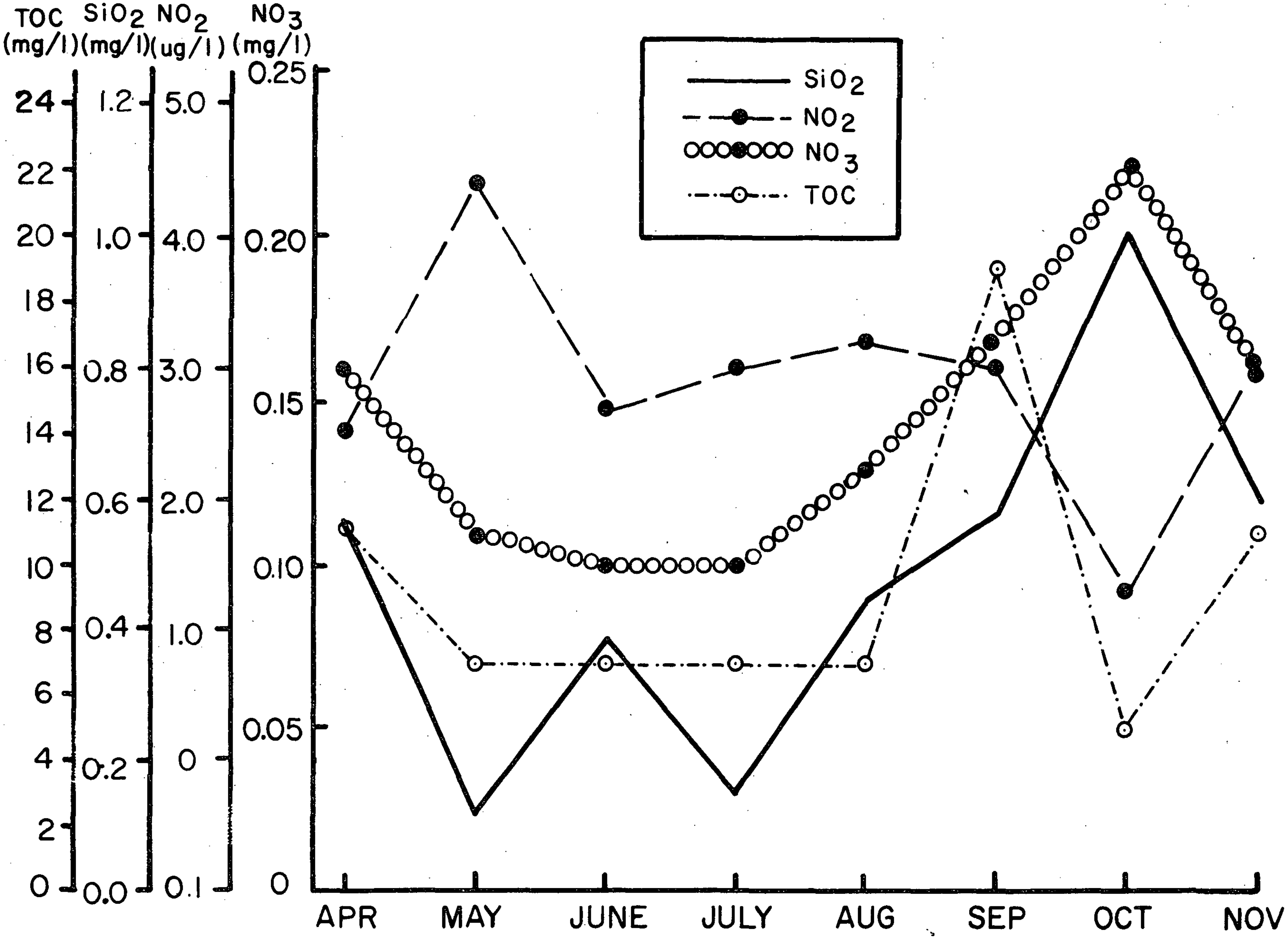

Figure 2.7 Seasonal distribution of total organic carbon (TOC), soluble silica (SiO_2), nitrite (NO_2) and nitrate (NO_3) at inshore Location 2 MID near the Kewaunee Nuclear Power Plant in 1973.

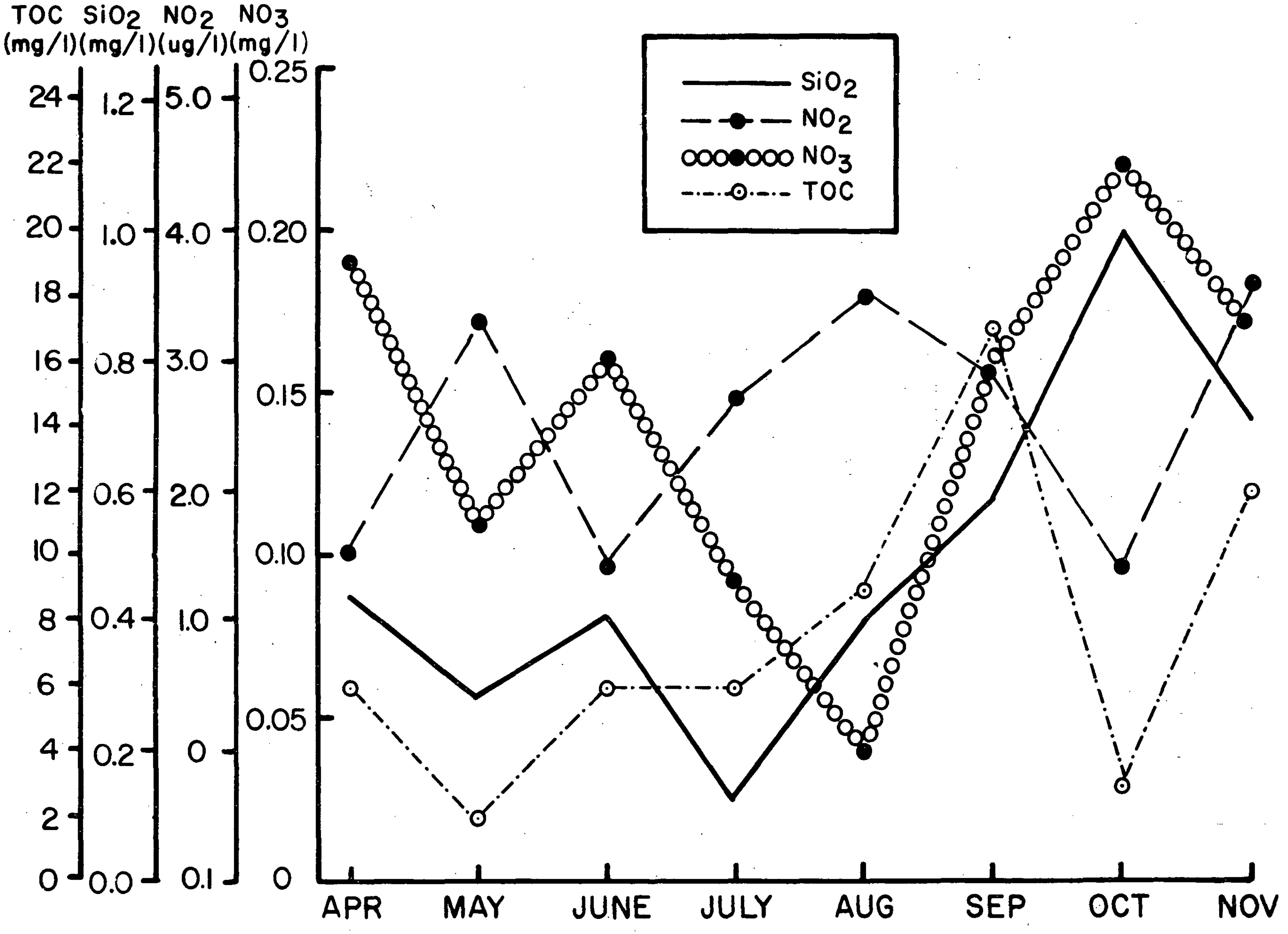

Figure 2.8 Seasonal distribution of total organic carbon (TOC), soluble silica (SiO_2), nitrite (NO2) and nitrate (NO3) at an offshore Location 14 TOP near the Kewaunee Nuclear Power Plant in 1973.

Ammonia values measured in 1973 were very uniform and exhibited a narrow range from <0.01 to 0.03 mg/l-N (Table 2.11). In general, the ammonia data displayed no seasonal or spatial distribution. Ammonia values were comparable to values obtained during the 1972 study.

Nitrate values ranged from 0.02 to 0.29 mg/l-N (Table 2.11). During June, nitrate values were higher at Transect V than Transect I. In August, nitrate values were higher inshore than offshore. Data obtained in August and September were higher for bottom than top samples and may be a result of the thermocline present during these months. Nitrate values decreased during the summer months showing seasonal trends similar to those of soluble silica (Figures 2.7 and 2.8). Nitrate values for 1973 were slightly below those of 1972, but typical of Lake Michigan waters.

Nitrite values ranged from 0.0006 to 0.0060 mg/l-N (Table 2.11). During April, nitrite values were higher at Transect I than Transect V. Higher values for nitrite at inshore locations than offshore locations were noted in June. In August and September, nitrite values were higher in top samples than in bottom samples. During this same time period, values for nitrate were higher in the bottom samples. This stratification of nitrogen species may be due to the presence of the thermocline during these two months as discussed previously. An inverse relationship existed between nitrate and nitrite values at both the inshore and offshore locations (Figures 2.7 and 2.8). This relationship may be related to oxidizing conditions or bacteriological activity converting nitrites to nitrates (Hutchinson 1967). Nitrite values during 1973 were very

Table2.11Yearly means and ranges for nitrate (NO_3), nitrite (NO_2), ammonia (NH_3) and total organic nitrogen values in samples collected from Lake Michigan near the Kewaunee Nuclear Power Plant in 1973.

Location		NO_3 (mg/l-N)	NO_2 (mg/l-N)	NH_3 (mg/l-N)	Total Organic Nitrogen (mg/l)
2 Mid	mean	0.14	0.0029	0.01	0.28
	range	0.09 - 0.22	0.0010 - 0.0049	0.01 - 0.03	0.20 - 0.39
7 Top	mean	0.15	0.0026	0.01	0.25
	range	0.08 - 0.21	0.0008 - 0.0047	<0.01 - 0.03	0.19 - 0.31
7 Bottom	mean	0.14	0.0026	0.01	0.26
	range	0.09 - 0.23	0.0009 - 0.0046	<0.01 - 0.03	0.17 - 0.35
11 Mid	mean	0.15	0.0028	0.01	0.27
	range	0.06 - 0.24	0.0010 - 0.0045	<0.01 - 0.02	0.21 - 0.35
12 Top	mean	0.14	0.0025	0.01	0.25
	range	0.05 - 0.22	0.0010 - 0.0040	<0.01 - 0.02	0.15 - 0.32
12 Bottom	mean	0.15	0.0026	0.01	0.26
	range	0.07 - 0.24	0.0007 - 0.0040	<0.01 - 0.02	0.19 - 0.33
14 Top	mean	0.14	0.0026	0.01	0.22
	range	0.03 - 0.22	0.0012 - 0.0039	<0.01 - 0.02	0.16 - 0.28
14 Mid	mean	0.15	0.0026	0.01	0.23
	range	0.10 - 0.21	0.0009 - 0.0041	<0.01 - 0.02	0.17 - 0.31
14 Bottom	mean	0.16	0.0025	0.01	0.26
	range	0.10 - 0.24	0.0008 - 0.0048	<0.01 - 0.02	0.20 - 0.37
16 Top	mean	0.14	0.0029	0.01	0.25
	range	0.03 - 0.22	0.0010 - 0.0060	<0.01 - 0.02	0.21 - 0.31
16 Bottom	mean	0.17	0.0026	0.01	0.26
	range	0.10 - 0.29	0.0010 - 0.0044	<0.01 - 0.02	0.15 - 0.43
20 Mid	mean	0.17	0.0025	0.01	0.30
	range	0.10 - 0.24	0.0008 - 0.0042	<0.01 - 0.02	0.14 - 0.73
23 Top	mean	0.14	0.0027	0.01	0.22
	range	0.02 - 0.23	0.0010 - 0.0046	<0.01 - 0.02	0.15 - 0.30
23 Mid	mean	0.17	0.0025	0.01	0.24
	range	0.08 - 0.29	0.0010 - 0.0041	<0.01 - 0.02	0.16 - 0.33
23 Bottom	mean	0.15	0.0022	0.01	0.26
	range	0.06 - 0.25	0.0010 - 0.0036	<0.01 - 0.02	0.17 - 0.33
24 Top	mean	0.14	0.0025	0.01	0.22
	range	0.03 - 0.26	0.0013 - 0.0045	<0.01 - 0.02	0.10 - 0.29
24 Mid	mean	0.14	0.0025	0.01	0.23
	range	0.10 - 0.20	0.0010 - 0.0039	<0.01 - 0.02	0.10 - 0.28
24 Bottom	mean	0.15	0.0021	0.01	0.23
	range	0.06 - 0.25	0.0006 - 0.0037	<0.01 - 0.02	0.16 - 0.31

similar to those obtained during 1972 and are typical of Lake Michigan.

Total organic nitrogen ranged from 0.10 to 0.73 mg/l-N (Table 2.11). In October, total organic nitrogen values were higher at Transect V than Transect I. During May, August, September and October organic nitrogen values were higher at inshore locations than offshore locations. The seasonal distribution of total organic nitrogen follows other weather-dependent parameters (Figure 2.5). Lake sediments have been shown to contain significant amounts of organic nitrogen (Austin and Lee 1973, and Table 2.10). There does not appear to be any relationship between total organic nitrogen and other nutrients or phytoplankton abundance. Total organic nitrogen values measured during 1973 were slightly higher than those values from 1972, but were typical of Lake Michigan water. Because nutrient parameters have similar trends at both inshore and offshore locations, they do not appear to be related to wave activity but are more likely a function of biological productivity. None of the weather-dependent nutrient parameters exhibited any uniform trends at the offshore location (Figure 2.8). This situation would be expected since the offshore locations are less susceptible to bottom scouring from wave action.

E. Indicators of Organic Material

The indicators of organic material monitored during this study included biochemical oxygen demand (B.O.D.), chemical oxygen demand (C.O.D.) and total organic carbon (T.O.C.).

Biochemical oxygen demand ranged from <0.5 to 3.5 mg/l (Table 2.12). During June, August and September, B.O.D. values were slightly

Table 2.12. Yearly means and ranges for biochemical oxygen demand (B.O.D.), chemical oxygen demand (C.O.D.), and total organic carbon (T.O.C.) values in samples collected from Lake Michigan near the Kewaunee Nuclear Power Plant in 1973.

Location		B.O.D. (mg/l)	C.O.D. (mg/l)	T.O.C. (mg/l)
2 Mid	mean	1.8	6.6	9
	range	0.9 - 2.9	3.3 - 9.7	3 - 20
7 Top	mean	1.9	5.2	8
	range	0.6 - 3.0	3.0 - 8.8	2 - 16
7 Bottom	mean	1.8	5.9	8
	range	0.5 - 3.0	3.5 - 8.1	2 - 20
11 Mid	mean	1.9	6.1	9
	range	0.5 - 3.2	4.1 - 9.4	2 - 20
12 Top	mean	2.0	5.8	8
	range	0.5 - 3.5	4.0 - 7.8	1 - 24
12 Bottom	mean	1.8	6.9	8
	range	0.6 - 3.0	4.7 - 11	2 - 21
14 Top	mean	1.7	6.4	8
	range	0.7 - 2.7	3.8 - 9.2	1 - 19
14 Mid	mean	1.8	7.3	7
	range	0.8 - 2.7	4.5 - 12	3 - 19
14 Bottom	mean	1.9	6.4	8
	range	1.0 - 2.8	5.0 - 9.0	2 - 18
16 Top	mean	1.8	7.2	7
	range	0.5 - 3.2	4.8 - 11	1 - 17
16 Bottom	mean	1.7	7.0	8
	range	0.5 - 3.0	3.1 - 11	1 - 22
20 Mid	mean	1.9	6.8	8
	range	0.6 - 3.1	1.7 - 10	2 - 24
23 Top	mean	1.7	7.1	7
	range	0.7 - 3.0	1.5 - 12	2 - 15
23 Mid	mean	1.7	6.9	7
	range	0.9 - 3.5	1.9 - 10	1 - 16
23 Bottom	mean	1.8	7.2	6
	range	0.9 - 3.1	5.1 - 10	1 - 12
24 Top	mean	1.6	6.8	7
	range	0.8 - 3.3	3.3 - 10	2 - 24
24 Mid	mean	1.7	8.5	7
	range	1.0 - 3.3	5.5 - 12	1 - 16
24 Bottom	mean	1.8	7.9	8
	range	1.0 - 3.2	6.5 - 10	2 - 20

higher for bottom samples than top samples. During the other months, the B.O.D. values varied little among locations and depths, with slightly higher values, if present, associated with offshore bottom locations. During June, August and September, a thermocline existed which may have contributed to the higher B.O.D. values and the lower values of D.O. in the hypolimnion as previously discussed. No apparent relationship between B.O.D. and other indicators of organic matter was evident. The values for B.O.D. measured during 1973 were lower than values measured during 1972, but were typical of Lake Michigan waters.

Values for C.O.D. ranged from 1.5 to 12 mg/l (Table 2.12). In June, C.O.D. values were higher at Transect I than Transect V and were higher for bottom samples than top samples. The values for C.O.D. may be weather-dependent since during September, when lake conditions were particularly turbid, C.O.D. values were higher at the inshore locations than offshore locations. This was consistent with conclusions drawn from 1972 data concerning C.O.D. The C.O.D. values obtained during 1973 were generally in good agreement with data obtained during the previous two years (Tables 2.6 and 2.7) and are typical of Lake Michigan waters.

The T.O.C. values measured during 1973 ranged from 1 to 24 mg/l (Table 2.12). The values for T.O.C. did not exhibit any dependence on distance from shore or depth. The seasonal trend for T.O.C. data, for both inshore and offshore locations were similar (Figures 2.7 and 2.8). The higher T.O.C. values may be associated with increased phytoplankton abundance. Values obtained for T.O.C. in 1973 were quite similar to data obtained in the previous two years (Tables 2.6 and 2.7).

F. Minerals

The minerals that were measured during this study include chloride, fluoride, sulfate, sodium, potassium, calcium and magnesium. Total hardness, although not a mineral, is discussed in this section because it is calculated from calcium and magnesium concentrations.

Chloride values ranged from 7.0 to 15.5 mg/l (Table 2.13). Chlorides remained exceptionally stable throughout the study period, with only May data exhibiting higher values than other months. There were no seasonal or spatial effects for chloride. Chloride values during 1973 agreed very well with data from the area for the previous two years (Tables 2.6 and 2.7).

Values for fluoride were relatively constant throughout this study, ranging from 0.09 to 0.16 mg/l (Table 2.13). Values for fluoride varied randomly throughout the year with the highest values obtained during April and June. Any spatial or seasonal distribution was not evident. Fluoride values for 1973 were very similar to those obtained during 1972 (Table 2.6).

Values for sulfate ranged from 14.2 to 22.8 mg/l. The seasonal trend for sulfate values shown in Figure 2.9 for inshore Location 2 was typical for sulfate at all locations. The similar seasonal trends for both specific conductance and sulfate suggest that the two parameters are related. No apparent spatial distribution was evident for sulfate. Sulfate values for 1973 agreed with data from 1972 (Table 2.6).

Table 2.13 Yearly means and ranges for chloride (Cl^-), flouride (F^-), sulfate ($SO_4^=$) and sodium (Na) values in samples collected from Lake Michigan near the Kewaunee Nuclear Power Plant in 1973.

Location		Cl^- (mg/l)	F^- (mg/l)	$SO_4^=$ (mg/l)	Na (mg/l)
2 Mid	mean	8.0	0.11	17.9	4.5
	range	7.0 - 15.5	0.09 - 0.14	17.0 - 20.6	4.2 - 4.6
7 Top	mean	7.5	0.11	19.4	4.5
	range	7.0 - 9.0	0.09 - 0.14	18.0 - 21.4	4.3 - 4.6
7 Bottom	mean	7.5	0.11	19.0	4.5
	range	7.0 - 10.0	0.09 - 0.16	17.5 - 22.0	4.2 - 4.8
11 Mid	mean	7.5	0.11	18.5	4.5
	range	7.0 - 9.5	0.09 - 0.14	15.7 - 20.0	4.2 - 4.8
12 Top	mean	7.5	0.11	19.0	4.5
	range	7.0 - 9.5	0.09 - 0.14	17.5 - 21.0	4.2 - 4.8
12 Bottom	mean	8.0	0.11	18.6	4.5
	range	7.0 - 11.0	0.09 - 0.15	16.4 - 20.5	4.2 - 4.8
14 Top	mean	7.5	0.11	18.3	4.5
	range	7.0 - 10.0	0.09 - 0.15	15.8 - 21.2	4.2 - 4.7
14 Mid	mean	7.5	0.11	19.0	4.5
	range	7.0 - 10.0	0.09 - 0.14	15.4 - 22.8	4.2 - 4.7
14 Bottom	mean	8.0	0.11	18.5	4.5
	range	7.0 - 11.0	0.09 - 0.14	15.0 - 22.5	4.2 - 4.7
16 Top	mean	7.5	0.11	18.3	4.5
	range	7.0 - 10.0	0.09 - 0.14	15.0 - 20.5	4.3 - 4.8
16 Bottom	mean	8.0	0.11	18.3	4.5
	range	7.0 - 10.5	0.09 - 0.14	14.2 - 21.0	4.2 - 4.7
20 Mid	mean	8.0	0.11	18.3	4.5
	range	7.0 - 10.0	0.09 - 0.14	15.0 - 21.0	4.2 - 4.7
23 Top	mean	7.5	0.11	18.5	4.5
	range	7.0 - 10.0	0.09 - 0.14	15.8 - 21.0	4.2 - 4.7
23 Mid	mean	8.0	0.11	18.1	4.5
	range	7.0 - 10.0	0.09 - 0.14	15.5 - 20.0	4.2 - 4.8
23 Bottom	mean	8.0	0.11	18.9	4.5
	range	7.0 - 11.0	0.09 - 0.14	15.2 - 19.5	4.2 - 4.8
24 Top	mean	8.0	0.11	18.2	4.5
	range	7.0 - 11.0	0.09 - 0.14	15.0 - 20.0	4.2 - 4.7
24 Mid	mean	8.0	0.11	18.2	4.5
	range	9.0 - 11.0	0.09 - 0.14	14.8 - 20.0	4.2 - 4.7
24 Bottom	mean	8.0	0.11	18.3	4.5
	range	7.0 - 11.0	0.09 - 0.14	14.8 - 21.0	4.3 - 4.7

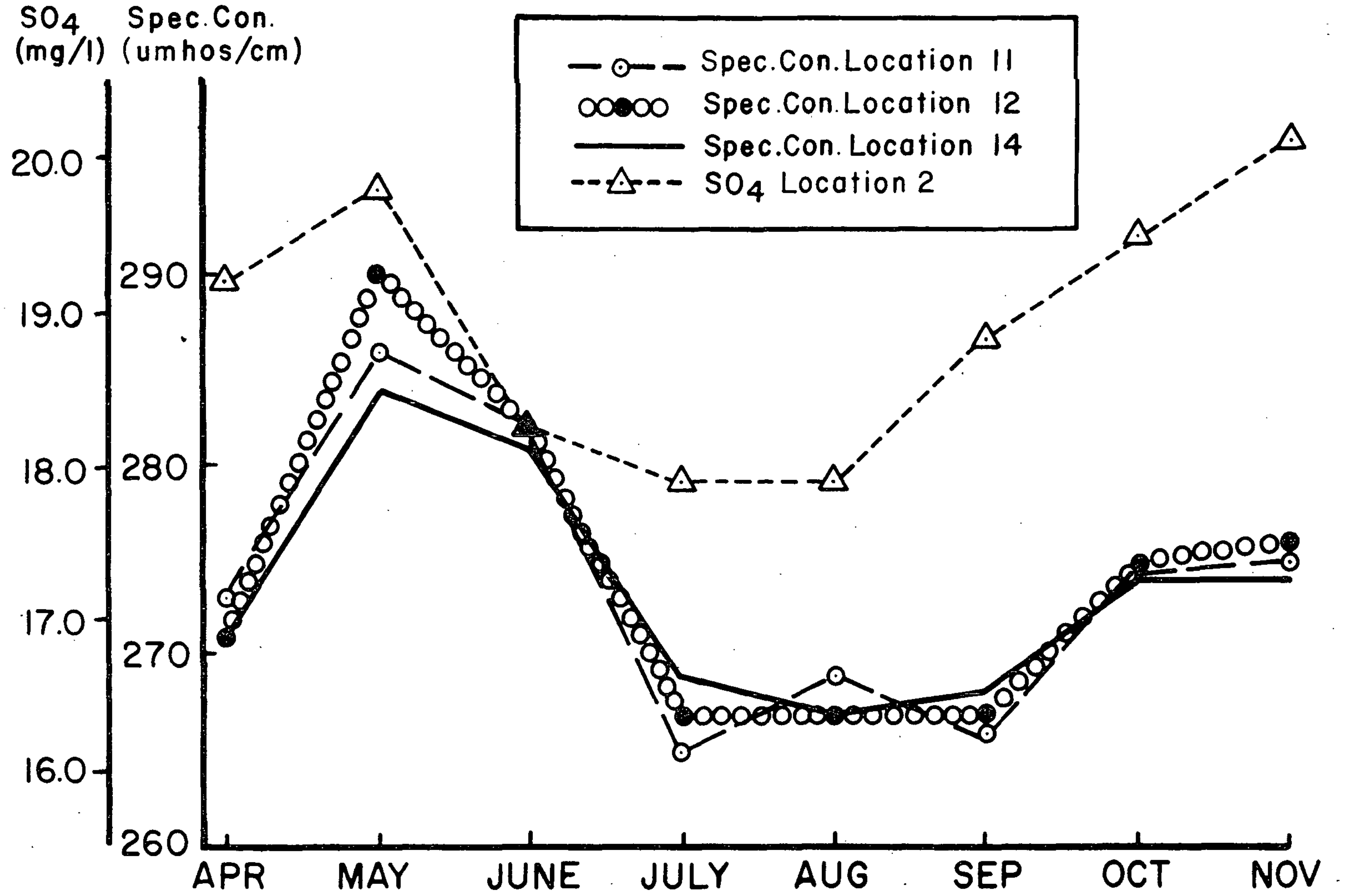

Figure 2.9 - Seasonal distribution of sulfate (SO_4) at the inshore Location 2 MID and specific conductance along Transect III.

Sodium values during 1973 were within the narrow range of 4.2 to 4.8 mg/l. No seasonal trend for sodium was evident with values randomly fluctuating from month to month as illustrated by sodium values from samples collected at Location 2 (Figure 2.10). A spatial distribution of sodium was not present and all locations averaged 4.5 mg/l throughout the year. Data obtained during 1973 were remarkably consistent with data obtained in 1972 (Table 2.6).

Potassium values ranged from 1.0 to 2.0 mg/l (Table 2.14). The seasonal distribution of potassium values (Figure 2.10) may be influenced by wave action since it is similar to seasonal distributions for other weather-dependent parameters (Figure 2.5). In April, potassium values were slightly higher at inshore locations and north of the Plant. The values for potassium, calcium and magnesium appear to be related in that they all exhibit very similar seasonal trends (Figure 2.10) and all show relatively high values in bottom sediments (Table 2.10). Potassium data from 1972 also led to the conclusion that this parameter is influenced by wave activity and turbulence. Potassium data collected in 1973 were comparable to data from 1972 (Table 2.6) and are typical of Lake Michigan waters.

Calcium concentrations during 1973 ranged from 29 to 41 mg/l (Table 2.14). Calcium values seemed to be somewhat related to wave activity since they were slightly higher at inshore locations, especially during periods of heavy wave activity in April, September and November (Figure 2.10). The data were similar to 1971 and 1972 data.

Magnesium values closely parallel calcium values (Figure 2.10), and

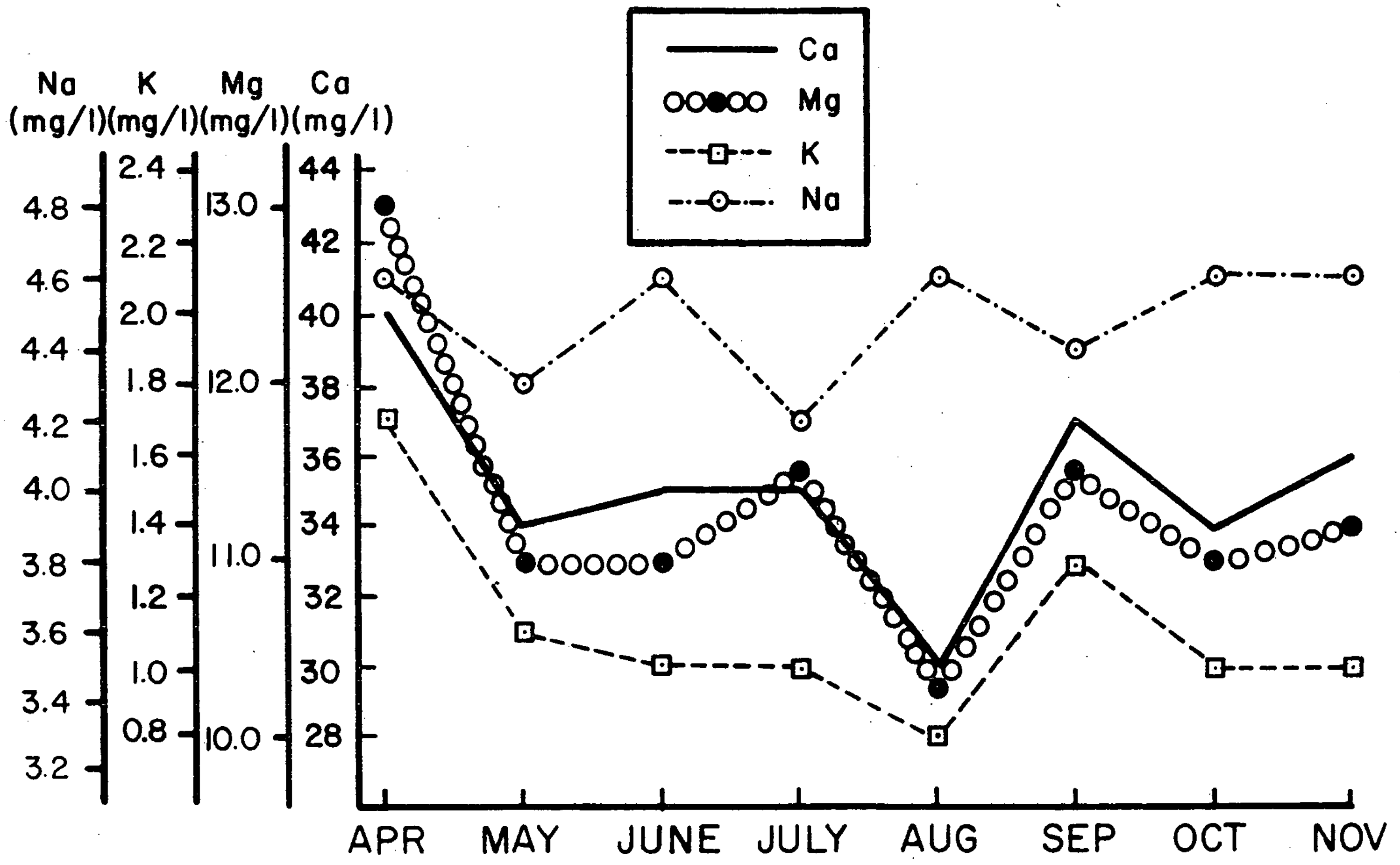

Figure 2.10 - Seasonal distribution of sodium (Na), potassium (K), magnesium (Mg), and calcium (Ca) at the inshore Location 2 MID.

Table 2.14Yearly means and ranges for potassium (K), calcium (Ca), magnesium (Mg) and total hardness values in samples collected from Lake Michigan near the Kewaunee Nuclear Power Plant in 1973 .

Location		K (mg/l)	Ca (mg/l)	Mg (mg/l)	Total Hardness (mg/l-$CaCO_3$)
2 Mid	mean	1.3	35	11.3	135
	range	1.0 - 2.0	29 - 41	10.0 - 13.0	114 - 156
7 Top	mean	1.2	35	11.3	134
	range	1.0 - 1.5	30 - 40	10.5 - 13.0	118 - 153
7 Bottom	mean	1.2	35	11.4	134
	range	1.0 - 1.5	30 - 40	10.0 - 13.0	116 - 153
11 Mid	mean	1.3	36	11.5	136
	range	1.0 - 1.8	30 - 40	10.5 - 13.0	120 - 153
12 Top	mean	1.2	35	11.3	134
	range	1.0 - 1.4	30 - 40	10.9 - 13.0	120 - 153
12 Bottom	mean	1.2	35	11.3	133
	range	1.0 - 1.7	30 - 41	10.0 - 14.0	116 - 160
14 Top	mean	1.2	34	10.9	130
	range	1.0 - 1.4	30 - 38	10.0 - 12.0	116 - 144
14 Mid	mean	1.1	34	10.9	131
	range	1.0 - 1.5	30 - 39	10.0 - 12.0	116 - 147
14 Bottom	mean	1.2	35	11.2	134
	range	1.0 - 1.4	30 - 39	10.8 - 13.0	120 - 161
16 Top	mean	1.2	35	11.3	135
	range	1.0 - 1.5	30 - 41	10.0 - 14.0	116 - 160
16 Bottom	mean	1.2	35	11.6	135
	range	1.0 - 1.6	29 - 41	10.0 - 14.0	114-160
20 Mid	mean	1.2	35	11.7	136
	range	1.0 - 1.4	29 - 40	10.0 - 14.0	114 - 157
23 Top	mean	1.2	34	11.1	131
	range	1.0 - 1.4	30 - 38	10.5 - 13.0	118 - 148
23 Mid	mean	1.1	34	11.1	131
	range	1.0 - 1.3	29 - 38	10.5 - 12.0	116 - 144
23 Bottom	mean	1.2	34	11.1	131
	range	1.0 - 1.4	29 - 38	10.0 - 12.1	114 - 144
24 Top	mean	1.1	34	10.9	131
	range	1.0 - 1.3	29 - 38	9.5 - 12.0	111 - 144
24 Mid	mean	1.2	34	11.0	131
	range	1.0 - 1.4	29 - 39	9.5 - 13.6	114 - 151
24 Bottom	mean	1.1	34	11.1	131
	range	1.0 - 1.3	29 - 39	10.5 - 13.0	116 - 148

both parameters exhibit the same seasonal distribution. The range of magnesium values measured during 1973 was from 9.5 to 14.0 mg/l. Values for magnesium were frequently higher for inshore locations which is an indication that this parameter was also weather-dependent. The magnesium data are considered typical of Lake Michigan.

Total hardness values closely paralleled those of both calcium and magnesium. The seasonal distribution of total hardness values, if plotted, would appear essentially the same as the data for calcium and magnesium in Figure 2.10. Hardness is partially dependent on the amount of turbidity in the water since hardness values were frequently higher for inshore locations than offshore locations, especially during periods of prolonged intense wave activity. The same conclusion was reached on the basis of data collected during 1972. Hardness values for 1973 ranged from 111 to 161 mg/l-$CaCO_3$ which is considered "hard" water in a qualitative sense (Hem 1971). Hardness values obtained during 1973 are quite similar to those obtained during 1972.

G. pH and Alkalinity

The pH measurements taken during 1973 were within the narrow range 7.6 to 8.4 (Table 2.15). Values for pH were lowest in April and highest during the summer months. During periods of strong thermal stratification in June, August, September and October, pH values were lower in bottom samples than in top samples. The lower pH values are the result of the production of carbon dioxide during microbiological oxidation of organic matter and correspond to the lower values of oxygen in the hypolimnion during the presence of the

Table 2.15 Yearly means and ranges for pH, total alkalinity and phenolphthalein alkalinity values in samples collected from Lake Michigan near the Kewaunee Nuclear Power Plant in 1973.

Location		pH	Total Alkalinity (mg/l-CaCO3)	Phenolphthalein Alkalinity (mg/l-CaCO3)
2 Mid	mean	8.3	111	0
	range	8.1 - 8.4	104 - 135	0 - 2
7 Top	mean	8.2	110	0
	range	8.0 - 8.4	102 - 128	0 - 2
7 Bottom	mean	8.2	110	0
	range	8.0 - 8.4	105 - 121	0 - 2
11 Mid	mean	8.2	109	0
	range	8.0 - 8.4	104 - 117	0 - 2
12 Top	mean	8.2	109	0
	range	8.0 - 8.4	103 - 118	0 - 2
12 Bottom	mean	8.2	109	0
	range	7.9 - 8.4	103 - 120	0 - 2
14 Top	mean	8.2	109	0
	range	7.8 - 8.4	104 - 117	0 - 2
14 Mid	mean	8.2	109	0
	range	7.9 - 8.4	104 - 115	0 - 2
14 Bottom	mean	8.1	108	0
	range	7.8 - 8.4	104 - 115	0 - 2
16 Top	mean	8.2	109	0
	range	7.9 - 8.4	104 - 117	0 - 2
16 Bottom	mean	8.2	110	0
	range	7.9 - 8.4	104 - 118	0 - 2
20 Mid	mean	8.2	109	0
	range	7.9 - 8.4	104 - 116	0 - 2
23 Top	mean	8.2	108	0
	range	7.8 - 8.4	102 - 113	0 - 2
23 Mid	mean	8.2	109	0
	range	7.7 - 8.4	103 - 116	0 - 1
23 Bottom	mean	8.1	109	0
	range	7.7 - 8.4	104 - 112	0 - 2
24 Top	mean	8.2	109	0
	range	7.7 - 8.4	103 - 115	0 - 2
24 Mid	mean	8.2	108	0
	range	7.6 - 8.4	103 - 116	0 - 2
24 Bottom	mean	8.2	109	0
	range	7.8 - 8.3	104 - 115	0 - 0

thermocline. In general, the 1973 pH data were typical of previous data obtained from the general area (Tables 2.6, 2.7, and 2.9).

Phenolphthalein alkalinity data ranged from 0 to 2 mg/l-$CaCO_3$ during the entire 1973 study (Table 2.15). Most of the non-zero values were obtained during summer months when pH values exceeded 8.3.

Total alkalinity values ranged from 102 to 135 mg/l-$CaCO_3$ (Table 2.15). Total alkalinity data generally corresponded to the pH data in that values were highest during the spring and fall, and lowest during the summer months. Several near-bottom samples exhibited higher values for alkalinity particularly during the month of September. Alkalinity data obtained during 1973 agreed well with data obtained from the area during previous years (Tables 2.6 and 2.7).

H. Trace Metals

The trace metals determined during this study included iron, manganese, mercury, lead, copper, zinc, total chromium, cadmium, nickel, arsenic and boron.

Iron showed an extremely wide range of concentrations from 0.002 to 0.95 mg/l (Table 2.16). Iron concentration is influenced by the turbulence of the water, and its seasonal pattern correlated well with other weather-dependent parameters, particulary turbidity (Figure 2.5). A strong relationship between iron and turbidity values was not apparent at the offshore surface Location 14 (Figure 2.6) which was usually least turbid. Higher iron values were obtained for inshore locations and bottom samples, especially during periods of prolonged

Table 2.16 Yearly means and ranges for iron (Fe), manganese (Mn) and mercury (Hg) values in samples collected from Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant in 1973.

Location		Fe (mg/l)	Mn (µg/l)	Hg (µg/l)
2 Mid	mean	0.20	6	0.06
	range	0.010 - 0.92	2 - 17	<0.05 - 0.19
7 Top	mean	0.14	4	0.24
	range	0.030 - 0.49	2 - 8	<0.05 - 2.9
7 Bottom	mean	0.078	5	0.07
	range	0.024 - 0.32	1 - 16	<0.05 - 0.15
11 Mid	mean	0.19	7	0.06
	range	0.036 - 0.48	3 - 17	<0.05 - 0.09
12 Top	mean	0.095	4	0.06
	range	0.029 - 0.31	2 - 6	<0.05 - 0.10
12 Bottom	mean	0.16	4	0.12
	range	0.016 - 0.85	2 - 6	<0.05 - 1.0
14 Top	mean	0.025	2	0.08
	range	0.005 - 0.042	1 - 2	<0.05 - 0.28
14 Mid	mean	0.027	2	0.06
	range	0.004 - 0.10	1 - 3	<0.05 - 0.10
14 Bottom	mean	0.044	2	0.11
	range	0.007 - 0.21	1 - 3	<0.05 - 0.66
16 Top	mean	0.13	4	0.07
	range	0.005 - 0.65	1 - 9	<0.05 - 0.27
16 Bottom	mean	0.20	6	0.07
	range	0.019 - 0.95	2 - 16	<0.05 - 0.12
20 Mid	mean	0.20	7	0.07
	range	0.031 - 0.74	2 - 15	<0.05 - 0.13
23 Top	mean	0.027	2	0.08
	range	0.002 - 0.060	1 - 3	<0.05 - 0.22
23 Mid	mean	0.027	2	0.11
	range	0.008 - 0.056	1 - 4	<0.05 - 0.80
23 Bottom	mean	0.046	3	0.07
	range	0.009 - 0.21	2 - 7	<0.05 - 0.13
24 Top	mean	0.033	2	0.07
	range	0.005 - 0.055	1 - 4	<0.05 - 0.17
24 Mid	mean	0.025	2	0.08
	range	0.004 - 0.050	1 - 3	<0.05 - 0.20
24 Bottom	mean	0.031	3	0.07
	range	0.005 - 0.068	1 - 6	<0.05 - 0.12

turbulence in April, September and November. Most of the iron present during turbid water conditions was a constituent of suspended or colloidal solids which readily settle out during quiescent periods. This fact is evidenced by the wide range of iron values encountered, and the relatively low and constant color values, which are indicative of dissolved iron concentrations. Iron values from 1973 were generally lower than those reported for 1972. Several other weather-dependent parameters were generally lower in 1973 than 1972, indicating calmer lake conditions during the 1973 sampling periods.

Manganese concentrations ranged from 1 to 17 μg/l (Table 2.16). Manganese was similar to iron and other weather-dependent parameters, displaying the same general seasonal trends (Figure 2.5). The variations in manganese values were not as pronounced as those of iron. Manganese values were higher for inshore locations and also were higher for bottom samples when waters were relatively turbid. Values for manganese measured during 1973 were comparable to data collected during 1972. Similar observations regarding iron and manganese were made and discussed in the 1971 and 1972 reports.

Mercury values during 1973 ranged from <0.05 to 2.9 μg/l with most values falling in the low end of this range (Table 2.16). There were no seasonal or spatial distributions for mercury. Mercury values measured during 1973 were substantially lower than values measured during 1972.

Values for lead, copper, and zinc displayed rather wide ranges throughout the 1973 study (Table 2.17). No particular seasonal or spatial

Table 2.17. Yearly means and ranges for lead (Pb), copper (Cu), zinc (Zn) and total chromium values in samples collected from Lake Michigan near the Kewaunee Nuclear Power Plant in 1973.

Location		Pb (μg/l)	Cu (μg/l)	Zn (μg/l)	Total Chromium (μg/l)
2 Mid	mean	3	1.6	9	2
	range	<1 - 9	0.7 - 3.3	1 - 30	1 - 7
7 Top	mean	4	1.7	12	2
	range	<1 - 19	0.8 - 2.8	1 - 29	1 - 3
7 Bottom	mean	5	1.4	14	2
	range	<1 - 23	0.7 - 2.3	1 - 30	1 - 3
11 Mid	mean	4	1.7	14	2
	range	<1 - 19	0.9 - 3.2	1 - 41	1 - 5
12 Top	mean	3	1.5	13	2
	range	<1 - 12	0.8 - 2.2	1 - 80	1 - 3
12 Bottom	mean	3	1.3	15	2
	range	<1 - 14	0.8 - 1.9	1 - 71	1 - 4
14 Top	mean	7	1.2	13	2
	range	<1 - 21	0.6 - 1.9	1 - 38	1 - 3
14 Mid	mean	5	1.0	11	1
	range	<1 - 23	0.4 - 2.1	1 - 28	1 - 3
14 Bottom	mean	5	1.3	10	2
	range	<1 - 17	0.6 - 3.9	1 - 29	1 - 3
16 Top	mean	5	1.6	9	2
	range	<1 - 18	0.8 - 2.4	1 - 30	1 - 3
16 Bottom	mean	5	1.7	13	2
	range	<1 - 14	0.5 - 2.8	1 - 30	1 - 3
20 Mid	mean	11	2.5	20	2
	range	<1 - 120	1.0 - 4.9	4 - 86	1 - 3
23 Top	mean	4	1.8	13	2
	range	<1 - 20	0.9 - 3.0	1 - 78	1 - 4
23 Mid	mean	5	1.3	12	2
	range	<1 - 20	0.3 - 2.7	1 - 35	1 - 4
23 Bottom	mean	7	1.2	14	2
	range	<1 - 48	0.5 - 2.4	2 - 51	1 - 3
24 Top	mean	5	1.2	10	2
	range	<1 - 33	0.5 - 2.4	1 - 58	1 - 3
24 Mid	mean	5	1.0	15	2
	range	<1 - 26	0.1 - 2.1	1 - 38	1 - 5
24 Bottom	mean	4	1.0	9	2
	range	<1 - 17	0.3 - 3.2	1 - 35	1 - 3

patterns with respect to any of these three metals were evident. Copper values were lower than 1972 values but lead and zinc values were comparable to data collected during 1972 (Table 2.6).

Total chromium, cadmium, nickel and arsenic were found at low concentrations throughout the present study (Tables 2.17 and 2.18). Most data were at or only slightly above analytical detection limits for this group of metals. Data obtained this year were in good agreement with data accumulated during 1972 (Table 2.6).

Boron values for 1973 ranged from 0.01 to 0.12 mg/l (Table 2.18). No apparent seasonal or spatial distribution for boron was evident and data accumulated for 1973 were very similar to the 1972 data (Table 2.6).

I. Bacteria

The types of bacteria monitored during this study included those associated with the bacterial standard plate count at 20C and the bacterial standard plate count at 35C, as well as total coliform bacteria, fecal coliform bacteria and fecal streptococci bacteria.

Bacterial standard plate counts at 20 and 35C exhibited wide ranges, with values from 490 to 6,900,000, and 130 to 4,500,000 organisms per 100 ml, respectively (Table 2.19). Bacterial standard plate counts at both 20 and 35C were substantially higher at locations south of the Plant than at those to the north. The other bacterial data also showed similar distributions, indicating that the area south of the Plant may be receiving more surface drainage or

Table 2.18. Yearly means and ranges for cadmium (Cd), nickel (Ni), arsenic (As) and boron (B) values in samples collected from Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant in 1973 .

Location		Cd (µg/l)	Ni (µg/l)	As (µg/l)	B (mg/l)
2 Mid	mean	0.1	1	1	0.03
	range	<0.1 - 0.3	<1 - 1	<1 - 3	0.01 - 0.05
7 Top	mean	0.1	1	1	0.03
	range	<0.1 - 0.2	<1 - 1	<1 - 3	0.02 - 0.07
7 Bottom	mean	0.1	1	1	0.04
	range	<0.1 - 0.2	<1 - 1	<1 - 3	0.01 - 0.10
11 Mid	mean	0.1	1	1	0.04
	range	<0.1 - 0.2	<1 - 1	<1 - 3	0.01 - 0.11
12 Top	mean	0.1	1	1	0.04
	range	<0.1 - 0.2	<1 - 1	<1 - 1	0.01 - 0.12
12 Bottom	mean	0.1	1	1	0.03
	range	<0.1 - 0.4	<1 - 1	<1 - 3	0.01 - 0.07
14 Top	mean	0.1	1	1	0.03
	range	<0.1 - 0.3	<1 - 1	<1 - 3	0.01 - 0.06
14 Mid	mean	0.1	1	1	0.03
	range	<0.1 - 0.7	<1 - 3	<1 - 2	0.01 - 0.07
14 Bottom	mean	0.1	1	1	0.03
	range	<0.1 - 0.1	<1 - 1	<1 - 4	0.01 - 0.09
16 Top	mean	0.1	1	1	0.03
	range	<0.1 - 0.2	<1 - 1	<1 - 4	0.01 - 0.05
16 Bottom	mean	0.1	1	1	0.03
	range	<0.1 - 0.2	<1 - 1	<1 - 2	0.01 - 0.05
20 Mid	mean	0.1	1	1	0.03
	range	<0.1 - 1.6	<1 - 2	<1 - 2	0.01 - 0.05
23 Top	mean	0.1	1	1	0.03
	range	<0.1 - 0.6	<1 - 2	<1 - 2	0.01 - 0.06
23 Mid	mean	0.1	1	1	0.03
	range	<0.1 - 0.2	<1 - 2	<1 - 3	0.01 - 0.05
23 Bottom	mean	0.1	1	1	0.04
	range	<0.1 - 0.2	<1 - 2	<1 - 2	0.01 - 0.09
24 Top	mean	0.1	1	1	0.03
	range	<0.1 - 0.9	<1 - 1	<1 - 2	0.01 - 0.08
24 Mid	mean	0.1	1	1	0.03
	range	<0.1 - 0.2	<1 - 2	<1 - 2	0.01 - 0.07
24 Bottom	mean	0.1	1	1	0.03
	range	<0.1 - 0.1	<1 - 1	<1 - 3	0.01 - 0.10

Table 2.19. Yearly means[a] and ranges for bacterial standard plate counts at both 20 C and 35 C and total coliform bacteria values in samples collected from Lake Michigan near the Kewaunee Nuclear Power Plant in 1973.

Location		Standard Plate Count at 20 C (No./100 ml)	Standard Plate Count at 35 C (No./100 ml)	Total Coliform (No./100 ml)
2 Mid	mean	15900	3620	5
	range	3500 - 36000	500 - 28000	0 - 31
7 Top	mean	23200	3900	10
	range	4500 - 500000	540 - 36000	3 - 40
7 Bottom	mean	18200	5000	9
	range	4900 - 57000	420 - 500000	0 - 54
11 Mid	mean	31000	3200	12
	range	11000 - 76000	440 - 81000	1 - 72
12 Top	mean	19600	3700	7
	range	5900 - 81000	460 - 1700000	0 - 34
12 Bottom	mean	21800	3800	12
	range	4400 - 73000	180 - 96000	3 - 150
14 Top	mean	9400	2100	3
	range	2100 - 58000	240 - 34000	0 - 34
14 Mid	mean	9500	3100	2
	range	1600 - 79000	250 - 1300000	0 - 35
14 Bottom	mean	48000	5400	7
	range	5800 - 880000	310 - 83000	0 - 58
16 Top	mean	26100	5500	18
	range	6400 - 95000	460 - 69000	0 - 100
16 Bottom	mean	26900	4400	12
	range	5100 - 100000	310 - 100000	3 - 90
20 Mid	mean	127000	14000	12
	range	44000 - 760000	350 - 690000	0 - 36
23 Top	mean	34800	17000	7
	range	1400 - 510000	180 - 330000	0 - 800
23 Mid	mean	40800	17000	7
	range	1000 - 690000	300 - 650000	0 - 350
23 Bottom	mean	63000	27000	8
	range	2800 - 6900000	300 - 340000	0 - 89
24 Top	mean	5000	2000	4
	range	490 - 51000	330 - 26000	0 - 4300
24 Mid	mean	7600	6500	9
	range	1600 - 49000	130 - 4400000	0 - 490
24 Bottom	mean	12700	9100	8
	range	3800 - 93000	340 - 4500000	0 - 59

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[a] Bacteria data means are expressed as geometric means defined as $\sqrt[n]{(a_1)(a_2)(a_3)\ldots(a_n)}$

effluents. Values of nearly all standard plate counts at 20C were higher than at 35C by an order of magnitude or more. This situation is commonly encountered with soil bacteria (Environmental Protection Agency 1971) and indicates that the natural flora of the lake are adapted to cooler water temperatures and are predominant. Standard plate count data at 20 and 35C may be related to weather conditions and turbidity. Higher counts were observed at inshore locations and in bottom samples, especially during periods of heavy wave activity. This fact was also apparent in data collected during 1972. Standard plate counts at 20C are comparable to data obtained during 1972. Standard plate counts at 35C averaged an order of magnitude lower in 1973 than in 1972 (Table 2.6).

Total coliform bacteria counts, measured during 1973, ranged from 0 to 4300 organisms per 100 ml, with the majority of the geometric mean values being below 10 per 100 ml. This indicates that little agricultural or industrial sewage is present in the area. Total coliform bacteria were more numerous in samples from locations south of the Plant than to the north, following a distribution similar to that of bacterial standard plate counts. Total coliform bacteria, which are characteristically present in soil, had higher counts for inshore and bottom location samples, particularly during periods of rough lake conditions.

Fecal coliform and fecal streptococci bacteria displayed narrow ranges and low average values during 1973 (Table 2.20). Generalizations on the source of bacterial loading can be made from the fecal coliform to fecal

Table 2.20. Yearly means and ranges for fecal coliform and fecal streptococci bacteria values in samples collected from Lake Michigan near the Kewaunee Nuclear Power Plant in 1973.

Location		Fecal Coliform (No./100 ml)	Fecal Streptococci (No./100 ml)
2 Mid	mean	1	2
	range	0 - 3	0 - 14
7 Top	mean	2	3
	range	0 - 11	0 - 18
7 Bottom	mean	1	2
	range	0 - 5	0 - 15
11 Mid	mean	2	3
	range	0 - 4	1 - 22
12 Top	mean	2	2
	range	0 - 10	0 - 8
12 Bottom	mean	1	3
	range	0 - 19	0 - 16
14 Top	mean	1	1
	range	0 - 20	0 - 30
14 Mid	mean	1	1
	range	0 - 1	0 - 4
14 Bottom	mean	1	1
	range	0 - 11	0 - 9
16 Top	mean	1	2
	range	0 - 6	0 - 13
16 Bottom	mean	1	3
	range	0 - 7	0 - 11
20 Mid	mean	1	3
	range	0 - 12	0 - 47
23 Top	mean	1	2
	range	0 - 4	0 - 6
23 Mid	mean	1	2
	range	0 - 5	0 - 4
23 Bottom	mean	1	2
	range	0 - 3	0 - 11
24 Top	mean	1	2
	range	0 - 15	0 - 11
24 Mid	mean	1	2
	range	0 - 2	0 - 8
24 Bottom	mean	1	1
	range	0 - 1	0 - 9

streptococci ratio (Geldreich and Kenner 1969). This ratio for data collected from the study area was normally between 0.5 and 1.0 which indicates that most bacterial pollution in the area is derived from surface runoff of livestock and poultry wastes. Fecal coliform data are comparable to data obtained previously during preoperational studies in 1971 and 1972. Fecal streptococci values averaged an order of magnitude below those values obtained during 1971 and 1972 (Tables 2.6 and 2.7). Bacterial data from the area were generally higher during the summer months than during the spring or fall.

J. Miscellaneous Parameters

The parameters discussed in this category include specific conductance, filtrable residue, nonfiltrable residue, total residue, true color, turbidity, hydrazine and morpholine.

Specific conductance values measured for 1973 ranged from 258 to 290 µmhos/cm (Table 2.21). Values were lower in the summer months and higher during spring and fall (Figure 2.9). This same seasonal trend was evident during 1972, and in other published data from the area (Table 2.9). The seasonal trend was similar at all three locations representing the three depths sampled, which suggested that this parameter was not affected by short-term weather conditions. While specific conductance values generally correlate with total dissolved solids levels and major constituents such as minerals, the only mineral values in the present study which correlated well with specific conductance values were those of sulfates. However, this may be due to the fact that values for conductance depend on dissolved ions

Table 2.21 Yearly means and ranges for nonfiltrable residue (TSS), filtrable residue (TDS) and specific conductance values in samples collected from Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant in 1973.

Location		TSS (mg/l)	TDS (mg/l)	Specific Conductance (µmhos/cm)
2 Mid	mean	11	169	274
	range	<1 - 44	157 - 195	265 - 290
7 Top	mean	8	162	274
	range	1 - 22	147 - 178	261 - 286
7 Bottom	mean	8	161	274
	range	1 - 24	144 - 179	262 - 285
11 Mid	mean	14	164	275
	range	6 - 23	142 - 187	266 - 289
12 Top	mean	5	164	274
	range	<1 - 13	147 - 179	266 - 287
12 Bottom	mean	10	163	275
	range	1 - 55	145 - 182	267 - 288
14 Top	mean	2	163	273
	range	<1 - 7	146 - 183	267 - 284
14 Mid	mean	3	161	274
	range	<1 - 8	145 - 176	266 - 284
14 Bottom	mean	4	162	275
	range	<1 - 14	144 - 186	268 - 284
16 Top	mean	8	163	274
	range	<1 - 39	134 - 196	266 - 287
16 Bottom	mean	12	169	274
	range	1 - 45	152 - 187	266 - 287
20 Mid	mean	13	168	276
	range	1 - 31	143 - 187	264 - 289
23 Top	mean	3	166	275
	range	<1 - 11	151 - 183	267 - 286
23 Mid	mean	3	165	274
	range	<1 - 13	145 - 186	267 - 284
23 Bottom	mean	4	169	276
	range	<1 - 18	150 - 188	268 - 287
24 Top	mean	2	161	274
	range	<1 - 8	141 - 182	266 - 287
24 Mid	mean	3	162	273
	range	<1 - 8	142 - 178	258 - 288
24 Bottom	mean	4	165	275
	range	<1 - 12	142 - 183	261 - 288

in solution, whereas the concentrations of some of the minerals (e.g. sodium, potassium, calcium and magnesium) were measured as total (dissolved plus particulate) concentrations. Specific conductance values measured in 1973 were higher than in 1972, 1971 and than other values reported for the area (Tables 2.6, 2.7 and 2.9).

Values for filtrable residue ranged from 134 to 196 mg/l (Table 2.21). Values for this parameter showed no seasonal or spatial trends, and were comparable with data from 1972 (Table 2.6).

Nonfiltrable residue exhibited a wide range of values from <1 to 55 mg/l (Table 2.21). Because it is a measure of the suspended matter, this parameter is strongly dependent on weather conditions and water turbulence. Values were higher for inshore locations and bottom samples, and seasonal trends in the data closely paralleled values for turbidity and other weather-dependent parameters.

Values for total residue were somewhat dependent on turbidity because the parameter is partially a measure of nonfiltrable residue. Values for this parameter ranged from 136 to 237 mg/l (Table 2.22).

True color values exhibited a narrow range of 1 to 5 units (Table 2.22). Generally higher values occurred during the spring when prolonged bottom scouring may have led to the solution of certain constituents which could impart color to the water. The same conclusions were drawn from 1972 data which were quite similar to 1973 data (Table 2.6).

Values for turbidity shown in Table 2.22 displayed the wide range of

Table 2.22 Yearly means and ranges for total residue(TS), turbidity and true color values in samples collected from Lake Michigan near the Kewaunee Nuclear Power Plant in 1973.

Location		TS (mg/l)	Turbidity (J.T.U.)	True Color (units)
2 Mid	mean	180	16	3
	range	162 - 235	3 - 44	1 - 6
7 Top	mean	170	11	2
	range	154 - 200	3 - 24	1 - 5
7 Bottom	mean	169	11	2
	range	146 - 198	3 - 25	1 - 4
11 Mid	mean	178	12	2
	range	153 - 210	5 - 25	1 - 5
12 Top	mean	170	8	2
	range	150 - 192	4 - 14	1 - 4
12 Bottom	mean	174	8	2
	range	148 - 237	3 - 20	1 - 5
14 Top	mean	163	3	2
	range	150 - 178	2 - 5	1 - 3
14 Mid	mean	164	3	2
	range	148 - 182	2 - 5	1 - 3
14 Bottom	mean	166	4	2
	range	148 - 200	1 - 9	1 - 4
16 Top	mean	171	9	2
	range	136 - 234	2 - 31	1 - 5
16 Bottom	mean	182	13	2
	range	156 - 232	3 - 38	1 - 5
20 Mid	mean	181	12	2
	range	150 - 208	3 - 30	1 - 4
23 Top	mean	169	3	2
	range	160 - 184	2 - 5	1 - 3
23 Mid	mean	169	3	2
	range	150 - 186	2 - 5	1 - 3
23 Bottom	mean	172	4	2
	range	154 - 188	2 - 11	1 - 3
24 Top	mean	163	3	2
	range	144 - 184	2 - 5	1 - 3
24 Mid	mean	165	3	2
	range	142 - 182	2 - 5	1 - 3
24 Bottom	mean	169	4	2
	range	150 - 190	3 - 5	1 - 3

from 2 to 44 J.T.U. As mentioned previously, turbidity is strongly dependent on wave activity and bottom scouring and these processes account for the higher values observed for inshore locations and bottom samples. Seasonal turbidity patterns were very similar to those observed for other weather-related parameters (Figure 2.5). Turbidity values measured in 1973 were generally lower than those measured during the previous two years of the study, indicating that lake conditions may have been calmer while sampling the present study.

Hydrazine and morpholine were not detected during the present study. These parameters are related to Plant operation and are not normally expected to be present in Lake Michigan.

K. Special Chlorination Study

The residual chlorine values determined during the special chlorination experiments conducted on 19 and 20 June 1973 are presented in Tables 2.23 through 2.26.

During Experiment I, when the system was tested with a chlorine input calculated to give a residual of 0.1 mg/l at the point where the circulating waters enter Lake Michigan, a maximum residual of 0.44 mg/l was attained in pump 1A within 85 min while pump 1B showed no residual chlorine during the entire experiment. The residual chlorine levels in pump 1A never attained a constant value but rose to a peak and then decreased to a value of 0.20 mg/l. The residual chlorine levels in the condensers fluctuated at or near 0.1 mg/l, while the values at the discharge were nearly constant at 0.1 mg/l within 45 min. Within ten minutes after chlorination was discontinued, residual

Table 2.23. Residual chlorine data for Experiment I at the Kewaunee Nuclear Power Plant, 19 June 1973.

Time	Total Residual Chlorine (mg/l) Pump 1A	Pump 1B	Condenser 1A South	Condenser 1B North	Discharge
1025	<0.01	<0.01	-[a]	-[a]	<0.01
1035	<0.01	<0.01	-	-	<0.01
1045[b]	<0.01	<0.01	-	-	<0.01
1050	0.01	<0.01	-	-	0.02
1100	0.14	<0.01	-	-	0.06
1110	0.15	<0.01	-	-	0.05
1120	0.13	<0.01	-	-	0.05
1130	0.15	<0.01	0.10	0.13	0.11
1140	0.20	<0.01	0.05	-[a]	0.10
1150	0.38	<0.01	0.04	0.06	0.10
1200	0.20	<0.01	0.03	0.04	0.11
1210	0.44	<0.01	0.10	0.04	0.12
1220	0.28	<0.01	0.03	0.06	0.10
1230	0.28	<0.01	0.07	0.12	0.10
1240	0.20	<0.01	0.06	0.06	0.10
1245[c]	<0.01	<0.01	<0.01	<0.01	0.06
1255	<0.01	<0.01	<0.01	<0.01	<0.01

[a] Instrument malfunction.
[b] Chlorination started.
[c] Chlorination terminated.

Table 2.24. Residual chlorine data for Experiment II at the Kewaunee Nuclear Power Plant, 19 June 1973.

	Total Residual Chlorine (mg/l)				
Time	Pump 1A	Pump 1B	Condenser 1A South	Condenser 1B North	Discharge
1350	<0.01	<0.01	<0.01	<0.01	<0.01
1355	<0.01	<0.01	<0.01	<0.01	<0.01
1405[a]	<0.01	0.66	0.17	0.30	<0.01
1415	<0.01	<0.01	0.31	0.45	0.26
1425	3.08	0.04	0.91	0.92	1.04
1435	3.21	<0.01	0.94	1.43	1.13
1445	2.86	<0.01	0.86	1.42	1.00
1455	2.73	<0.01	0.84	1.64	1.10
1505	3.11	0.12	1.00	1.60	1.27
1515	2.51	0.16	0.81	1.52	1.21
1525	2.78	0.16	0.94	1.42	1.18
1535	3.25	0.11	0.70	1.42	1.07
1545	3.22	0.22	0.99	1.41	1.11
1555	3.07	0.15	0.79	1.13	1.04
1600[b]	3.24	0.23	0.73	1.07	1.09
1605	0.29	0.13	0.07	0.10	0.55
1615	0.20	0.13	0.09	0.08	0.15
1625	0.04	0.08	0.02	0.06	<0.01
1635	0.19	0.16	0.15	0.19	<0.01
1650[c]	0.34	0.08	0.01	0.11	<0.01

[a] Chlorination started.

[b] Chlorination terminated.

[c] Study terminated because pumps were shut off.

Table 2.25. Residual chlorine data for Experiment III at the Kewaunee Nuclear Power Plant, 20 June 1973.

	Total Residual Chlorine (mg/l)				
Time	Pump 1A[a]	Pump 1B	Condenser 1A South	Condenser 1B North	Discharge
0825	-	<0.01	<0.01	<0.01	<0.01
0835	-	<0.01	<0.01	<0.01	<0.01
0845[b]	-	<0.01	<0.01	<0.01	<0.01
0850	-	1.13	1.24	1.25	0.15
0900	-	1.15	1.32	1.27	1.30
0910	-	1.07	1.35	1.28	1.28
0920	-	1.12	0.90	0.92	1.17
0930	-	0.76	0.93	0.92	0.74
0940	-	0.54	0.61	0.90	0.67
0950	-	0.80	0.51	0.53	0.55
1000	-	0.58	0.50	1.27	0.09
1010	-	1.57	0.60	0.63	0.80
1020	-	0.75	-[c]	0.60	0.62
1030	-	0.52	0.62	0.57	0.56
1040	-	0.70	0.33	0.46	0.56
1050[d]	-	0.06	0.06	0.07	<0.01
1100	-	<0.01	<0.01	<0.01	<0.01
1110	-	<0.01	<0.01	<0.01	<0.01

[a] Pump 1A not in operation.

[b] Chlorination started.

[c] Sample contaminated.

[d] Chlorination terminated.

Table 2.26. Residual chlorine data for Experiment IV at the Kewaunee Nuclear Power Plant, 20 June 1973.

	Total Residual Chlorine (mg/l)				
Time	Pump 1A	Pump 1B	Condenser 1A South	Condenser 1B North	Discharge
1210	<0.01	<0.01	<0.01	<0.01	<0.01
1220	<0.01	<0.01	<0.01	<0.01	<0.01
1230	<0.01	<0.01	<0.01	<0.01	<0.01
1235	<0.01	<0.01	<0.01	<0.01	<0.01
1245[a]	<0.01	<0.01	<0.01	<0.01	<0.01
1250	0.10	<0.01	0.06	0.03	0.05
1300	0.12	<0.01	0.02	0.04	0.03
1310	0.13	<0.01	0.03	0.05	0.03
1320	0.50	<0.01	0.29	0.20	0.21
1330	0.54	<0.01	0.27	0.18	0.22
1340	0.42	<0.01	0.10	0.21	0.19
1350	0.15	<0.01	0.04	0.09	0.07
1400	0.13	<0.01	0.03	0.08	0.06
1410	0.18	<0.01	0.04	<0.01	0.06
1420	0.11	<0.01	0.04	1.10	0.06
1430	0.19	<0.01	0.04	0.05	0.06
1440	0.16	<0.01	0.04	0.05	0.03
1450[b]	<0.01	<0.01	<0.01	<0.01	<0.01
1500	<0.01	<0.01	<0.01	<0.01	<0.01

[a] Chlorination started.

[b] Chlorination terminated.

chlorine levels at the discharge had decreased to ambient values (<0.01 mg/l).

During Experiment II, the maximum chlorine feed rate was used and within 20 minutes, residual chlorine values ranging from 2.50 to 3.25 mg/l were observed at pump 1A. Values at pump 1B were much lower than at pump 1A but attained a maximum residual of 0.23 mg/l within 120 min and a reasonably constant level of 0.16 mg/l within 60 min. The condensers achieved the maximum residual chlorine in about 50 min, while the discharge achieved maximum chlorine residual within 60 min. Residual chlorine levels in the discharge returned to ambient values within 25 minutes after chlorination was terminated.

When pump 1A was shut down and the system was chlorinated with only pump 1B providing circulating water (Experiment III) a constant residual chlorine level of 1.1 mg/l was reached in 5 min. This residual was maintained for 30 min at which time the chlorine feed rate was reduced. At this time the residual chlorine level in pump 1B and the discharge decreased by approximately 0.4 mg/l but the condensers took about 20 min longer to show a decrease. At 0950 the recirculating water pump was turned off because of overheating and this resulted in a 1.0 mg/l rise in the residual chlorine level of pump 1B and a 0.7 mg/l rise in the level at the discharge. At 1015 the chlorine feed was reduced again and the residual chlorine in pump 1B began to stabilize at 0.7 mg/l with the discharge possessing a residual of 0.6 mg/l. Within 10 min after the termination of chlorination, residual chlorine values in the discharge had returned to ambient levels.

The final experiment (Experiment IV), involved manipulating the chlorine feed to produce maximum biocide efficiency in the condensers and minimum chlorine residual at the point of discharge. The chlorine feed was adjusted initially to produce a residual chlorine of 0.1 mg/l within 5 min in pump 1A. Pump 1B showed no residual chlorine. During this time the residual chlorine level in the discharge was no greater than 0.05 mg/l. At 1315 the chlorine feed was increased and the residual level at pump 1A increased to 0.5 mg/l while the residual chlorine level of the discharge rose to 0.2 mg/l. At 1345 the chlorine feed was reduced producing a residual of 0.15 mg/l in pump 1A with a corresponding residual of 0.07 mg/l in the discharge. This residual remained constant until 1450 when chlorination was terminated.

IV. Summary and Conclusions

1. The values of those water quality parameters measured in Lake Michigan near the Kewaunee Nuclear Power Plant were within the accepted limits of Wisconsin State Standards with the exception of several iron and turbidity values. Iron and turbidity values were high when meteorological conditions resulted in greater nearshore bottom scouring due to increased wave activity.

2. The outflow from the Kewaunee River had no apparent effect on water quality in Lake Michigan near KNPP.

3. The existence of a thermocline in the study area was influenced by weather conditions, and a thermocline was present during relatively quiescent periods in June, August, September and October. The distribution of D.O., soluble silica, B.O.D., and pH in the water column was influenced by the presence of the thermocline.

4. Nutrient parameters such as soluble silica, nitrate and nitrite, and total organic carbon were not directly related to phytoplankton abundance. An inverse relationship between nitrite and nitrate values was apparent. Silica values were stratified during the months when a thermocline was present and levels were higher for bottom samples than for top samples.

5. Weather-dependent parameters included total phosphorus, manganese, iron, nonfiltrable residue, turbidity, total organic nitrogen, calcium, potassium, and magnesium. Higher levels were apparent during turbulent periods and are related to the abundance of these constituents in the bottom sediments.

6. Bacterial values were higher in samples collected south of KNPP than north of it indicating that the southern area is receiving more surface run-off. Standard plate counts and coliform bacteria were related to weather conditions which caused turbid waters.

7. Several weather-dependent parameters including iron, total phosphorus and turbidity were higher in 1972 than during the 1973 study, indicating that lake conditions may have been calmer during the 1973 samplings. Other data from the area are quite similar to data from the previous preoperational studies conducted during 1971 and 1972, and to other data collected from the area.

8. The results of the special chlorination study showed that total residual chlorine levels in the circulating water system could be effectively controlled so that levels do not exceed 0.1 mg/l at the point of discharge to Lake Michigan.

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Chapter 3

PHYTOPLANKTON

Lloyd D. Everhart and Janice G. Rasgus

PREOPERATIONAL THERMAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR KEWAUNEE NUCLEAR POWER PLANT

THIRD ANNUAL REPORT
January-December 1973

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Chapter 3

PHYTOPLANKTON

Lloyd D. Everhart and Janice G. Rasgus

I. Introduction

This chapter presents 1973 preoperational baseline information on the phytoplankton community in Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant (KNPP). The specific objectives were:

1. to document species composition and abundance;
2. to determine normal spatial and temporal fluctuations in the phytoplankton population;
3. to identify statistically significant differences in population densities between locations; and
4. to compare this year's data with 1971 and 1972 data to determine natural yearly variations.

These data will be used as a base to which operational data may be compared in evaluating possible influences of the KNPP thermal effluent.

II. Field and Analytical Procedures

Duplicate water samples for phytoplankton analyses were collected monthly, April through November, at nine locations (Figure 1, Introduction). Sampling locations were positioned on the basis of depth and distance from the Plant. Three locations were along the 10-ft depth contour (inshore Locations 2, 11 and 20), three were along the 20-ft depth contour (middle Locations 7, 12 and 16), and three were along the 40-ft depth contour (offshore Locations 14, 23 and 24). Each sample was collected from 1m below the surface with a non-metallic Van Dorn water sampler, placed in a 1.9 liter polyethylene bottle, and preserved at the time of collection by the addition of 60 ml of "M^3" fixative (Meyer 1971).

The volume of sample processed for diatom analysis was dependent upon the turbidity and the abundance of organisms. The diatoms were cleaned using a concentrated nitric acid/potassium dichromate treatment (Hohn and Hellerman 1963), and collected on a 0.45µ HA Millipore filter (Holland 1969). A section of the filter was mounted on a slide, cleared with immersion oil and examined with phase contrast at 1250X magnification. A sufficient quantity (usually 400) of diatom valves was counted to estimate the density of the abundant species.

Phytoplankton other than diatoms were prepared for analysis by processing 875 ml of the preserved water sample. Each subsample was allowed to settle overnight after the addition of 10 ml of liquid detergent which acted as a surfactant (Mackenthun 1969); the subsample was then condensed to a final

200:1 concentration. An aliquot of the concentrated sample was analyzed in accordance with the Lackey scan technique (Lackey 1938) under bright field or phase contrast at 500X magnification. A sufficient quantity of phytoplankton reporting units was counted to estimate the density of all species.

Phytoplankton were recorded as numbers of reporting units per milliliter. A reporting unit consisted of each cell or frustule for unicellular species; a 100μ length of filament or trichrome for filamentous species; and four cells for each colonial species except Aphanocapsa, Aphanothece, and Microcystis which were reported in 50 cell units.

All organisms were identified to the lowest positive taxon, usually species, using taxonomic keys by Cleve-Euler (1951), Drouet (1968), Drouet and Daily (1956), Edmondson (1966), Hustedt (1930), Patrick and Reimer (1966), Prescott (1962, 1964), Smith (1950), Stoermer and Yang (1969), and Tiffany and Britton (1952).

A one-way analysis of variance (ANOVA) was applied to the data collected each month. An appropriate multiple comparison procedure (Tukey's or Scheffe's) was used following the ANOVA to isolate significant differences between any two locations. Comparisons were made either between locations along a given depth contour, or between locations along a given transect (inshore, middle and offshore locations).

Species diversity (Shannon 1948) was calculated monthly using phytoplankton data from each sampling location. The number of species and the number of individuals of each species in the sample influenced the diversity index (H).

The species content of the sample is referred to as the "species richness" component of diversity. The distribution of the number of individuals within a species is referred to as "equitability". Equitability or evenness (J) may range from 0.0 to 1.0 and is the highest when all species in the sample are present in nearly equal numbers. The species diversity, which may change from 0.0 to some positive number, usually less than 4.0, is increased both by increasing species richness and increasing evenness.

III. Results and Discussion

A. Phytoplankton Community Composition and Distribution

Phytoplankton collected near the Kewaunee Nuclear Power Plant during 1973 were represented by seven major algal divisions. The two most abundant divisions were Bacillariophyta (diatoms) and Cyanophyta (blue green algae). The Chlorophyta (green algae) and Chrysophyta (golden brown algae) were also commonly observed, but were much less abundant. The Euglenophyta (euglenoids), Pyrrhophyta (dinoflagellates), and Cryptophyta (blue and red flagellates) were only rarely present. The abundance and percent composition of total phytoplankton and of the four major phytoplankton divisions are shown in Table 3.1.

Included within the algal divisions were 309 taxa representing 95 genera (Appendix 3). Thirty-two of the taxa were considered dominants; that is, they composed more than 5% of the phytoplankton in any one sample collected during the study (Table 3.2). Twenty-two of the 32 dominant species were diatoms with the remaining dominants consisting of five species of blue green algae, three species of golden brown algae, and two species of flagellates. One-half of the dominant species were abundant for only a single month and only seven species appeared as dominants in four or more of the eight months in which sampling was conducted. These seven species, in order of decreasing dominance, consisted of Fragilaria crotonensis, Stephanodiscus sp., Fragilaria pinnata, Cyclotella stelligera, Tabellaria flocculosa, Asterionella formosa (all diatoms), and Coelosphaerium naegelianum (a blue green alga).

Table 3.1. Abundance and percent composition of total phytoplankton and major phytoplankton divisions collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Date Collected	Location	Total Phytoplankton Reporting Units/ml	Bacillariophyta Reporting Units/ml	Bacillariophyta Percent Composition	Chlorophyta Reporting Units/ml	Chlorophyta Percent Composition	Chrysophyta Reporting Units/ml	Chrysophyta Percent Composition	Cyanophyta Reporting Units/ml	Cyanophyta Percent Composition
13 Apr	2	2307	2203	95.5	6	0.3	72	3.1	26	1.1
	7	2037	1858	91.2	6	0.3	156	7.7	16	0.8
	11	1894	1728	91.2	8	0.4	132	7.0	24	1.3
	12	1768	1685	95.3	7	0.4	68	3.9	7	0.4
	14	2291	2181	95.2	12	0.5	89	3.9	9	0.4
	16	1931	1801	93.3	13	0.7	114	5.9	3	0.2
	20	1343	1243	92.6	10	0.8	81	6.1	8	0.6
	23	2192	2120	96.7	12	0.6	52	2.4	7	0.3
	24	2009	1926	95.9	13	0.6	55	2.7	12	0.6
Mean		1975	1861	94.2	10	0.5	91	4.6	12	0.6
22 May	2	2220	2112	95.2	26	1.2	46	2.1	34	1.5
	7	1355	1209	89.2	35	2.6	62	4.6	49	3.6
	11	1353	1253	92.6	53	3.9	34	2.5	13	1.0
	12	1382	1254	90.7	25	1.8	76	5.5	27	2.0
	14	1219	1081	88.7	21	1.7	96	7.9	21	1.7
	16	1243	1177	94.7	19	1.5	42	3.4	5	0.4
	20	2313	2182	94.3	37	1.6	64	2.8	30	1.3
	23	943	724	76.8	12	1.3	163	17.3	44	4.6
	24	1586	1489	93.9	42	2.7	51	3.2	3	0.2
Mean		1513	1387	91.7	30	2.0	70	4.6	25	1.7
26 Jun	2	1034	913	88.3	27	2.6	48	4.7	46	4.5
	7	1523	1416	93.0	33	2.2	22	1.4	51	3.4
	11	1760	1633	92.8	35	2.0	22	1.3	70	4.0
	12	1709	1637	95.8	33	1.9	4	0.2	36	2.1
	14	802	701	87.4	22	2.8	49	6.1	30	3.7
	16	2452	2348	95.8	34	1.4	24	1.0	47	1.9
	20	1478	1333	90.2	23	1.6	54	3.6	68	4.6
	23	926	783	84.6	27	2.9	68	7.3	48	5.2
	24	708	647	91.4	15	2.2	30	4.3	16	2.2
Mean		1377	1268	92.1	28	2.0	36	2.6	46	3.3

Table 3.1. Continued.

Date Collected	Location	Total Phytoplankton Reporting Units/ml	Bacillariophyta		Chlorophyta		Chrysophyta		Cyanophyta	
			Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition
24 July	2	964	878	91.1	16	1.7	57	5.9	11	1.1
	7	547	453	82.8	10	1.8	67	12.3	17	3.0
	11	1187	1103	92.4	10	0.9	65	5.5	9	0.7
	12	753	672	89.2	4	0.6	46	6.1	28	3.7
	14	332	260	78.2	10	2.9	52	15.6	9	2.7
	16	592	512	86.5	12	2.1	46	7.8	20	3.4
	20	851	798	93.8	14	1.6	31	3.6	6	0.8
	23	506	367	72.4	21	4.2	102	20.2	16	3.2
	24	624	492	78.8	19	3.0	97	15.5	15	2.4
Mean		706	615	87.1	13	1.8	63	8.9	15	2.1
28 Aug	2	1004	296	29.5	84	8.4	14	1.4	510	50.8
	7	1739	469	27.0	121	7.0	13	0.7	1022	58.9
	11	2079	937	45.1	128	6.2	38	1.8	912	43.8
	12	1461	455	31.1	113	7.7	47	3.2	754	51.6
	14	741	202	27.3	53	7.2	25	3.3	451	60.8
	16	1187	261	22.0	93	7.8	26	2.2	770	64.9
	20	1173	412	35.1	45	3.8	22	1.8	634	54.1
	23	830	324	39.1	52	6.3	33	4.0	400	48.2
	24	883	217	24.6	56	6.3	12	1.3	552	62.6
Mean		1233	397	32.2	83	6.7	26	2.1	667	54.1
26 Sept	2	2649	2496	92.2	30	1.1	4	0.2	111	4.2
	7	1066	890	83.5	35	3.3	20	1.9	100	9.4
	11	3373	3076	91.2	40	1.2	32	1.0	204	6.1
	12	1205	896	74.4	34	2.8	24	2.0	220	18.3
	14	733	532	72.5	26	3.5	5	0.6	146	20.0
	16	849	658	77.5	25	2.9	10	1.2	136	16.0
	20	2630	2425	92.2	30	1.1	19	0.7	139	5.3
	23	763	562	73.6	23	3.0	23	3.0	140	18.3
	24	1024	813	79.4	29	2.9	11	1.0	168	16.4
Mean		1588	1372	86.4	30	1.9	16	1.0	152	9.6

Table 3.1. Continued.

Date Collected	Location	Total Phytoplankton Reporting Units/ml	Bacillariophyta		Chlorophyta		Chrysophyta		Cyanophyta	
			Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition
23 Oct	2	781	586	75.0	20	2.6	1	0.1	129	16.5
	7	823	683	83.0	33	4.1	8	1.0	62	7.5
	11	1625	1429	88.0	21	1.3	12	0.7	131	8.1
	12	946	826	87.3	22	2.3	2	0.2	78	8.3
	14	539	366	67.8	27	4.9	4	0.7	105	19.5
	16	680	510	75.1	19	2.7	4	0.6	113	16.6
	20	1078	905	83.9	16	1.5	0	0.0	131	12.1
	23	536	384	71.7	14	2.5	0	0.1	106	19.8
	24	440	316	71.9	13	2.9	1	0.2	73	16.6
Mean		828	667	80.6	21	2.5	4	0.5	103	12.4
13 Nov	2	3517	3306	94.0	16	0.5	20	0.6	132	3.8
	7	867	714	82.4	17	2.0	10	1.1	62	7.2
	11	1366	1176	86.1	26	1.9	3	0.2	113	8.3
	12	1001	858	85.8	27	2.8	1	0.1	72	7.2
	14	540	373	69.2	19	3.5	11	2.0	66	12.2
	16	958	663	69.2	33	3.5	6	0.7	189	19.8
	20	1033	826	80.0	33	3.2	10	1.0	77	7.4
	23	722	417	57.8	20	2.7	11	1.5	144	19.9
	24	871	663	76.2	18	2.0	3	0.4	134	15.3
Mean		1208	1000	82.8	23	1.9	8	0.7	110	9.1
Yearly Mean		1304	1070	82.1	30	2.3	39	3.0	141	10.8

Table 3.2. Dominant species which composed 5% or more of the total phytoplankton at any location near the Kewaunee Nuclear Power Plant during 1973.

Taxa	Months							
	April	May	June	July	August	September	October	November
Bacillariophyta								
Cyclotella stelligera	X		X	X	X			
Fragilaria crotonensis	X	X	X	X	X	X	X	X
Fragilaria pinnata	X			X		X	X	X
Stephanodiscus minutus	X							
Stephanodiscus sp.	X	X	X			X	X	X
Tabellaria flocculosa	X	X	X	X				
Fragilaria intermedia	X							
Melosira italica		X				X	X	
Stephanodiscus binderanus		X						
Diatoma tenue var. *elongatum*		X						
Fragilaria capucina var. *mesolepta*		X						
Synedra filiformis		X	X	X				
Nitzschia acicularis		X						
Rhizosolenia eriensis		X						
Melosira islandica		X						
Asterionella formosa			X	X			X	X
Rhizosolenia longiseta			X					
Diatoma tenue				X				
Fragilaria capucina			X	X				
Nitzschia sp.				X		X		X
Cyclotella glomerata				X		X	X	
Cyclotella ocellata							X	
Cyanophyta								
Coelosphaerium naegelianum					X	X	X	X
Aphanothece castagnei					X			
Gomphosphaeria lacustris var. *compacta*					X			
Aphanothece nidulans					X			
Gomphosphaeria lacustris						X		
Chrysophyta								
Dinobryon cylindricum	X							
Dinobryon sociale		X		X				
Dinobryon divergens				X				
Miscellaneous								
Rhodomonas sp.					X			
Rhodomonas minuta var. *hannoplanctica*								X
Dominant Species Per Month	8	12	8	12	7	8	8	7

All of these species were abundant during the 1971 and 1972 preoperational studies at KNPP (Industrial BIO-TEST Laboratories, Inc. 1972 and 1973) and have also been reported during the past two years as major components of the phytoplankton community in southwestern Lake Michigan (Industrial BIO-TEST Laboratories, Inc. 1974; Mayhew and Barbour 1974).

Phytoplankton populations exhibited a bimodal seasonal distribution (Figure 3.1). Populations were largest in April (1975 reporting units/ml), least in July (706 units/ml), and then attained a second maximum in September (1588 units/ml). The largest standing crop (3517 units/ml), however, occurred in November (Location 2) while the smallest standing crop (332 units/ml) was observed in July (Location 14). The mean yearly density of phytoplankton was 1304 units/ml and consisted of 82% diatoms, 11% blue-green algae, 3% golden brown algae and 2% green algae (Table 3.1).

Phytoplankton tended to decrease in abundance from inshore to offshore locations, although this tendency was much more pronounced for the diatoms than for the other major algal divisions (Figure 3.1). In six of the eight sampling periods, diatoms were most abundant inshore whereas the other divisions attained their maximum density at the middle or offshore locations in at least five of the sampling periods. This trend has been noted in the two studies conducted previously in 1971 and 1972, and has been partially attributed to wave action which scours benthic diatoms from the underlying substates and incorporates them into the plankton.

Species diversity and evenness indices for phytoplankton collected

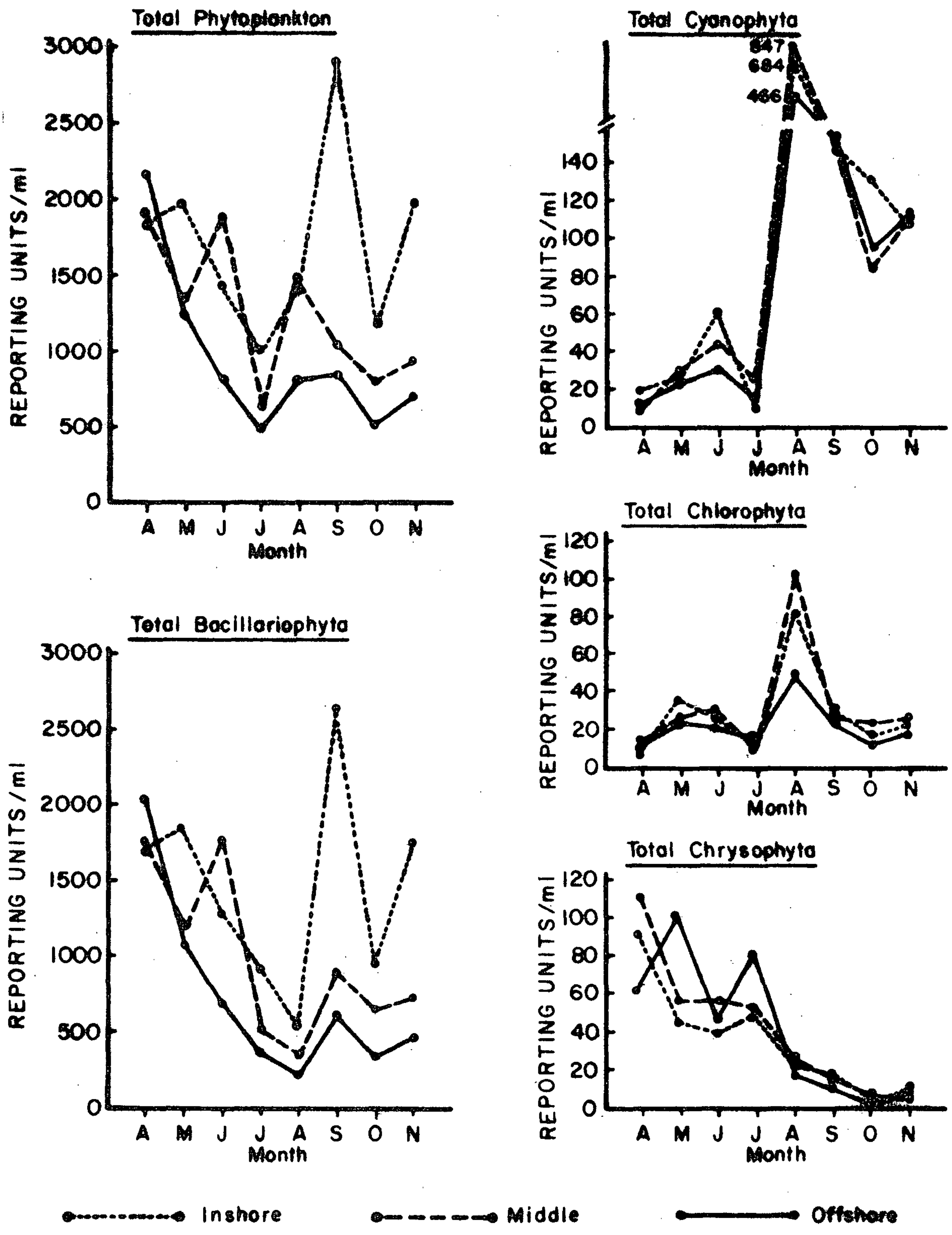

Figure 3. 1. Monthly variation in abundance of total phytoplankton and four major phytoplankton divisions collected near the Kewaunee Nuclear Power Plant. April-November 1973. Each value is the mean of three locations.

during the study ranged from 2.22 to 3.59 and from 0.56 to 0.83, respectively (Table 3.3). Annual means for the two indices were 2.99 and 0.75, respectively. Diversity and evenness values were generally higher in the fall than during the spring which reflects an opposite seasonal trend compared with phytoplankton abundance. The period of annual minimum phytoplankton abundance, which occurred in July, did not coincide with the period of seasonal low for diversity (2.72) and evenness (0.67), which occurred in August. It is interesting to note that the seasonal low in diversity and evenness occurred at a time when blue green algae were at their yearly maximum abundance and diatoms were at their yearly minimum abundance (Figure 3.1). At that time, two species of blue green algae (Coelosphaerium naegelianum and Aphanothece nidulans) represented a very large proportion (44%) of the phytoplankton and thereby caused a reduction in the diversity and evenness values.

Annual means for the two indices from each sampling location did not reveal any pronounced trends although two of the three lowest annual mean diversity values (2.81 and 2.94) were obtained at inshore locations (Table 3.3). Since phytoplankton abundance was highest and diversity was lowest inshore, a trend develops which suggests that the inshore assemblage was composed of fewer taxa and more individuals per taxon than the offshore assemblage.

Statistical analyses of total phytoplankton data revealed a number of significant differences ($P \leq 0.05$) in abundance between locations, but when differences occurred, they could be attributed to changes in one or more of the major algal divisions. Therefore, the discussion of such differences will be included in following sections of the report which address the major taxa.

Table 3.3. Diversity[a] (H) and Evenness (J) of phytoplankton collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April to November 1973.

Sampling Location	April		May		June		July		August		Sept		Oct		Nov		Annual Mean	
	H	J	H	J	H	J	H	J	H	J	H	J	H	J	H	J	H	J
2	2.83	0.72	2.82	0.72	2.81	0.78	2.84	0.74	2.72	0.68	2.87	0.69	3.12	0.79	2.49	0.58	2.81	0.71
7	2.86	0.75	3.04	0.78	2.85	0.76	3.11	0.81	2.62	0.61	3.55	0.82	3.13	0.78	3.12	0.77	3.04	0.76
11	2.81	0.74	3.10	0.81	2.97	0.77	3.07	0.78	3.03	0.73	3.08	0.71	3.15	0.76	3.13	0.76	3.04	0.76
12	2.88	0.77	2.93	0.78	2.65	0.73	3.14	0.79	2.81	0.69	3.59	0.81	3.10	0.76	3.18	0.77	3.04	0.76
14	2.75	0.74	3.09	0.79	2.90	0.80	2.44	0.70	2.79	0.70	3.29	0.79	3.39	0.83	3.24	0.81	2.99	0.77
16	2.77	0.73	2.88	0.78	2.35	0.67	2.80	0.72	2.22	0.56	3.53	0.82	3.33	0.83	3.15	0.75	2.88	0.73
20	2.62	0.71	2.79	0.72	2.95	0.79	3.11	0.80	2.66	0.69	3.08	0.74	2.99	0.76	3.30	0.80	2.94	0.75
23	2.70	0.72	3.07	0.78	3.05	0.81	2.60	0.73	2.79	0.69	3.44	0.82	3.26	0.81	3.16	0.78	3.01	0.78
24	2.79	0.75	2.99	0.76	2.73	0.75	2.56	0.71	2.61	0.65	3.40	0.80	3.23	0.81	2.90	0.71	3.15	0.74
Monthly Mean	2.78	0.74	2.97	0.77	2.81	0.76	2.85	0.76	2.72	0.67	3.31	0.78	3.19	0.79	3.07	0.75	2.99	0.75

[a] Shannon, C.E. 1948. A mathematical theory of communication. Bell system Tech. J. 27: 379-423, 623-56.

B. Spatial and Temporal Distribution of Major Taxa

1. Diatoms

Most changes in the total phytoplankton population were reflective of changes in diatom abundance (Figure 3. 1). Diatoms composed at least 80% of the mean phytoplankton abundance in all months except August when they represented only 32% of the phytoplankton population. Monthly means for diatoms ranged from 615 to 1861 reporting units/ml (July and April, respectively), except in August when they numbered only 397 units/ml. The largest single assemblage of diatoms (3306 units/ml) occurred in November at Location 2, and the smallest assemblage (202 units/ml) was present in August at Location 14.

There were at least 161 species identified throughout the study representing 31 genera of diatoms; however, very few of these taxa were important constituents of the phytoplankton community. As stated previously, 22 of the 32 dominant taxa in the study were diatoms. These 22 taxa dominated the phytoplankton community to such an extent that not more than two non-diatom taxa were dominant in any month, except August. Fragilaria crotonensis was the single most abundant taxon and was the only species which composed more than 5% of the assemblage in every month of the study. This species has been the first or second most prevalent phytoplankton organism in the Kewaunee area during the past two years. Other frequently encountered diatoms included Fragilaria pinnata, Stephanodiscus sp., Tabellaria flocculosa, Cyclotella stelligera and Asterionella formosa. These species were all abundant during 1972 also, but the order of dominance differed between the two years. The third and fourth most abundant species during 1972 (Rhizosolenia eriensis and Synedra filiformis) were only occasionally abundant in the present 1973 study. All of these species are widely distributed, commonly occur in Lake Michigan and tolerate a wide variety of trophic levels (Stoermer and Yang 1970).

Statistical analyses of diatom data revealed a very distinct pattern of significant differences ($P \leq 0.05$) between locations. Populations often differed between locations within a depth contour. Populations also always decreased from inshore, to middle, to offshore locations (Table 3.4). Significant differences occurred in every sampling period, except April, and usually involved the inshore diatom assemblage sampled at Locations 2, 11 and 20 (Table 3.5). During May and November, diatoms were significantly less abundant at Location 11 than at Locations 2 or 20. In the other six months, the pattern was reversed with the greatest diatom abundance at Location 11 and the least abundance at Locations 2 and 20.

Location 12 at the middle depth contour had significantly larger diatom populations in every month but April and May (Table 3.5). These differences were usually not among the middle contour locations but rather between locations along the same transect (for example, Location 12 and sampling Location 14 directly offshore from it). The low number of differences among the middle contour locations can probably be attributed to the fact that the three sampling locations are closer together than sampling locations along the other contours.

Table 3.4. Number of comparisons in which abundance at one location (inshore, middle or offshore) was significantly greater than at other locations (inshore, middle or offshore) for phytoplankton divisions in samples collected near Kewaunee Nuclear Power Plant, April-November 1973.

	Number of Comparisons with Greater Than (>) Abundance, by Location		
Algal Division and Locations	Inshore	Middle	Offshore
Total Phytoplankton			
Inshore	12	0[a]	0
Middle	3[a]	3	0[a]
Offshore	13	5[a]	5
Bacillariophyta (diatoms)			
Inshore	13	0[a]	0
Middle	4[a]	4	0[a]
Offshore	15	6[a]	3
Chlorophyta (green algae)			
Inshore	2	0[a]	1
Middle	1[a]	1	0[a]
Offshore	2	0[a]	3
Cyanophyta (blue green algae)			
Inshore	0	0[a]	1
Middle	0[a]	2	0[a]
Offshore	0	0[a]	2
Chrysophyta (golden brown algae)			
Inshore	7	1[a]	2
Middle	2[a]	5	1[a]
Offshore	1	0[a]	7

[a] Based on a total of eight comparisons as opposed to 24 comparisons for the other locations.

Table 3.5. Significant differences ($P \leq 0.05$) in the abundance of total phytoplankton and major phytoplankton divisions between sampling locations in Lake Michigan near the Kewaunee Nuclear Power Plant, 1973.

Taxa	April	May	June	July	August	September	October	November
Total Phytoplankton	NS[a]	11<2, 20 23<20, 24 2>24	11>2, 14 12>14 7<16	11>20, 12, 14 12>7, 14 14<24, 23 20>23	11>2, 20	11>12, 14, 2, 20 12>16, 14 24>23, 14 2>24 20>23	11>2, 12, 14, 20 24<2, 23 12>14	2>11 14<12, 11 2>20, 24
Total Bacillariophyta (diatoms)	NS	11<2, 20 23<20, 24 2>24	11>2, 14 12>14 7<16	11>2, 20, 12, 14 12>7, 14 24>14 2>24 20>23	11>2, 20, 14, 12 12>14, 16 7>16 23>14	11>2, 20, 12, 14 2>24 12>14 20>23	11>2, 12, 14, 20 12>14 20>23	2>11 14<11, 12 2>20, 24 20>23
Total Chlorophyta (green algae)	NS	11>2, 12, 14, 20 24>14, 23, 2 7>16 23<14, 20	NS	NS	NS	NS	NS	NS
Total Cyanophyta (blue-green algae)	NS	NS	NS	NS	NS	NS	NS	16>7, 12 24>23, 14 23>14
Total Chrysophyta (golden-brown algae)	NS	11<12, 14, 20 23>14, 20, 24 12>16 24>14	12<11, 14, 7 12>16 11<20 24<23	NS	NS	11>14, 20, 2 14<12, 23 16<7, 12 23>24 20>2	11>2, 12, 20	NS

Inshore Locations: 2, 11, 20
Middle Locations: 7, 12, 16
Offshore Locations: 14, 23, 24

[a] NS = not significant

Location 11 is directly in front of the Kewaunee Nuclear Power Plant, but since the Plant was not in operation (other than occasional testing) the significant population differences can only be attributed to natural factors. It is suggested that perhaps the prevailing along shore current (Chapter 1), in combination with the irregular shoreline adjacent to the Plant, produces an eddying effect that tends to concentrate the phytoplankton in the vicinity of Location 11.

2. Blue Green Algae

Blue green algae (Cyanophyta) were represented by at least 26 species within 12 genera during 1973 (Appendix 3). They were very sparse from April through July, never comprising more than 5.2% of any one sample (Table 3.1); however, in the months thereafter they were quite abundant and represented from 9 to 54% of the mean monthly abundance. Populations were at their maximum in August ranging from 400 to 1022 units/ml and representing 43 to 65% of the phytoplankton. The populations were quite uniformly distributed throughout the sampling area in all months, with significant differences between locations occurring only in November (Table 3.5). There were no apparent patterns to these differences.

Five species of blue greens represented more than 5% of the phytoplankton community at least once during 1973 (Table 3.2). Coelosphaerium naegelianum was dominant in the Kewaunee area in August and September and was the primary constituent of the heavy blue green pulse. This same species was dominant in the KNPP area in the fall months of 1971 and 1972, but it never comprised more than 18 or 40% of the phytoplankton in the respective years.

The blue green algal assemblage was considerably larger in 1973 than either of the two previous years. The largest abundance previously reported was 322 units/ml which is less than one-third the size reported in this study. Whether or not this is an indication of the natural year to year change or an indication of some other influence cannot be assessed at this time.

3. Golden Brown Algae

The golden brown algae (Chrysophyta) were represented by 25 species within 12 genera during 1973 (Appendix 3). This algal division was most abundant April through July when it composed >1 to 20% of the phytoplankton population with numbers ranging from 4 to 163 reporting units/ml (Figure 3.1 and Table 3.1). After July, golden browns never constituted more than 4% of the phytoplankton population, nor consisted of more than 47 units/ml. The yearly mean for all sampling periods was only 39 units/ml which represented 3% of the annual standing crop. The only dominant species were Dinobryon cylindricum, Dinobryon divergens and Dinobryon sociale (Table 3.2). Although these are the same dominant species as reported in 1972, they were less abundant in 1973 (163 versus 611 units/ml). This decrease was primarily due to a considerable reduction in numbers of D. divergens. All of these species commonly occur in Lake Michigan and predominate when nutrients have been depleted by other algal species (Hutchinson 1967).

Statistically significant differences in abundance involving golden brown algae occurred between locations in May, June, September and October. (Table 3.3). Differences occurred both between locations within each contour and between locations along a given transect (Table 3.4). As with the diatoms, differences frequently involved Location 11 where the abundance of golden browns were significantly greater than at other inshore locations in the fall (September and October), but significantly less than at least one of the other inshore locations in the spring (May and June). Other consistent trends are not apparent.

4. Green Algae

Green algae (Chlorophyta) was the second most diverse algal division (33 genera and 87 species) although its components never made up more than 9% of the phytoplankton population or numbered more than 128 reporting units/ml (Table 3.1). No single green algal species was dominant (more abundant than 5%) in the phytoplankton during the study. Maximum populations were present in August when the mean monthly abundance was 83 units/ml which represented about 7% of the plankton. The mean yearly abundance was only 30 units/ml which accounted for about 2% of the phytoplankton.

Species which were commonly present but which were never abundant included many representatives of the genera Scenedesmus sp., Ankistrodesmus sp. and Oocystis sp.

The only significant population differences between locations involving green algae occurred in May (Table 3.3). There was no pattern to these differences as they occurred between inshore, middle and offshore locations and between locations on a given contour without consistency (Table 3.4), and probably reflect natural patchiness in the phytoplankton community.

C. Relationship between Phytoplankton and Physicochemical Parameters

There was no apparent relationship between nutrient levels and phytoplankton abundance. Nutrient levels were high enough to support algal growth but not high enough to support nuisance blooms. Orthophosphate levels remained constant throughout the study while nitrite, nitrate and silica (SiO_2) levels fluctuated (Chapter 2). The monthly sampling schedule employed during this study was probably too infrequent to detect actual utilization of these nutrients by phytoplankton. A complete discussion of results of physical and chemical analyses performed near the Kewaunee Plant during 1973 is presented in Chapter 1 and Chapter 2, respectively.

IV. Summary and Conclusions

1. Seven major algal divisions were collected near the Kewaunee Nuclear Power Plant. The four major divisions, in decreasing order of abundance, included Bacillariophyta (diatoms), Cyanophyta (blue green algae), Chlorophyta (green algae) and Chrysophyta (golden brown algae).

2. Phytoplankton species composition changed very little from 1971 to 1973, with diatoms dominating all three years. Dominant diatom species during all three years included Fragilaria crotonensis, Fragilaria pinnata, Cyclotella stelligera, Tabellaria flocculosa, Asterionella formosa and Stephanodiscus sp.

3. Blue green algae were second in order of abundance. They were most abundant and were the dominant group in August. Coelosphaerium naegelianum was the most common blue green species collected in 1971, 1972 and 1973.

4. Green algae were the second most diverse algal division although they never composed more than 9% of the total phytoplankton at any sampling location. No green algal species were dominant.

5. Golden brown algae were less abundant in 1973 than in 1972, but the dominant species were the same. These included Dinobryon cylindricum, D. divergens, and D. sociale. Abundance of golden brown algae steadily declined from April through October and then increased slightly in November.

6. Phytoplankton populations at the inshore locations were generally significantly greater than at the offshore locations. This was especially true

for diatoms and golden brown algae.

7. Nutrient levels were sufficient to support algal growth but not nuisance blooms. Definite relationships between nutrient levels and phytoplankton abundance were not discernible.

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Chapter 4

ZOOPLANKTON

Janet M. Urry

PREOPERATIONAL THERMAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR KEWAUNEE NUCLEAR POWER PLANT

THIRD ANNUAL REPORT
January-December 1973

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Chapter 4

ZOOPLANKTON

Janet M. Urry

I. Introduction

The purpose of the study reported in this chapter was to continue the collection of preoperational baseline data on zooplankton populations in Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant (KNPP). Such preoperational data will be useful in determining the effect, if any, of effluents from the KNPP on the zooplankton populations by comparing these data with those collected after plant operation begins. The specific objectives of the 1973 zooplankton study were:

1. to determine the composition of the zooplankton community;
2. to characterize the zooplankton populations in Lake Michigan in the area of the KNPP in terms of natural seasonal fluctuations, and spatial variations between sampling locations, transects, and depth contours;
3. to compare the data gathered as a part of this study with those data from 1972 to identify natural year-to-year variability; and
4. to establish a data base to be used in assessing the effect of the thermal effluent on zooplankton following the start-up of KNPP.

Comparison of data presented herein with data collected in 1972 must be made in consideration of several major differences between the sampling design of the two studies:

1. Samples in 1972 were collected twice per week with two month

intervals between major sampling periods; this design made it possible to detect very short-term population fluctuations, but did not provide an assessment of month to month changes as was possible with the monthly sampling used in the present study;

2. Several locations were added in 1973 which were not included in 1972; and

3. Calculations of zooplankton populations in the present study were influenced by the inclusion of rotifers, which were not enumerated in 1972.

II. Field and Analytical Procedures

Four replicate zooplankton samples were collected monthly, May through November, at each of 15 locations (Figure 1, Introduction). Each sample was a composite of two simultaneous vertical tows using 30 cm diameter, conical, Nytex plankton nets of #12 mesh (120 μ aperture). Vertical tows were made from 3 m to the surface at the 10-ft depth (Locations 2, 6, 11, 15 and 20), from 6 m to the surface at the 20-ft depth (Locations 3, 7, 12, 16 and 21), and from 9 m to the surface at the 30-ft depth (Locations 4, 8, 13, 17 and 22). In April, four replicate samples were composited from 3 m vertical tows at each 10-, 20-, and 30-ft location, from 6 m tows at each 20-ft location, and from 9 m tows at each 30-ft location along Transects II, III and IV only. A total of 60 composite samples was collected on each field trip. Samples were preserved in 5% buffered formalin at the time of collection.

In the laboratory, each sample was concentrated or diluted to obtain a workable density of organisms. The sample was thoroughly mixed and a random subsample was withdrawn and placed in a counting chamber. Each month the same ratio of subsample volume to sample volume was maintained for each sample from a given depth. All rotifers and microcrustacea were counted. Species identifications were made of all the microcrustacea except immature copepods and certain taxonomically indistinct adult forms which were identified to the lowest possible taxon. Subsampling continued until 300 of the numerically dominant microcrustacea had been counted. Identifications were made with taxonomic keys by Brooks (1957, 1966), Czaika and Robertson (1968), Gannon (1970), and Wilson and Yeatman (1959). Population densities were reported as number of organisms per cubic meter of water (No./m^3).

Samples collected each month from similar depths were compared by subjecting the data for total zooplankton and major taxa to analysis of variance (ANOVA) tests. A nested one way ANOVA was applied to the data from April through July and a one way ANOVA was applied to the data from August through November. In addition, a nested factorial ANOVA was applied to the nine 3 m tows in April. All locations having significant differences were detected by Tukey's multiple comparison procedure. In all months, a Kruskal-Wallis non-parametric ANOVA was applied to the data from similar depths and appropriate multiple comparisons were made.

III. Results and Discussion

A complete listing of the results from all zooplankton analyses (species identification, density and percent composition) is presented in Appendix 4.

A. Composition of the Zooplankton

The zooplankton community in the area of the KNPP during 1973 consisted of Rotifera and Crustacea. The Crustacea were comprised of 37 species representing 10 genera of Copepoda and 14 genera of Cladocera (Table 4.1). The mean composition during the eight months of study consisted of 50% Copepoda, 36% Cladocera and 14% Rotifera. The proportions of the three major taxa in the zooplankton community varied monthly. Copepoda ranged from 6 to 85% of the total in July and June, respectively; Cladocera ranged from 1 to 73% in May and July, respectively; and Rotifera ranged from 1 to 65% in November and May, respectively (Table 4.2).

Fifteen of the 37 crustacean species encountered in 1973 were not reported from the area of the KNPP in 1972 (Table 4.1). Two of these species, Diaptomus siciloides and Daphnia pulex, have not been previously reported from the major basin of Lake Michigan (Gannon 1972). Diaptomus siciloides has been observed throughout most of the North American continent except for the extreme northern and eastern coastal areas (Wilson and Yeatman 1959). This species has been observed in samples from Lake Erie (Davis 1969) and Lake Ontario (Robertson 1966) and is present through the limnetic areas of southern Green Bay (Gannon 1972). The second species, Daphnia pulex, is normally a pond inhabitant with a distribution that includes most of North America

Table4. 1.Planktonic Crustacea collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April - November 1973

Copepoda
nauplii
calanoid copepodites
cyclopoid copepodites
Cyclops bicuspidatus thomasi S.A. Forbes
C. vernalis Fischer
Diaptomus ashlandi Marsh
D. minutus Lilljeborg
D. oregonensis Lilljeborg
D. sicilis S.A. Forbes
*D. siciloides Lilljeborg
Epischura lacustris S.A. Forbes
*Ergasilus chautauquaensis Fellows
*Eucyclops agilis (Koch)
Eurytemora affinis (Poppe)
Limnocalanus macrurus Sars
Mesocyclops edax (S.A. Forbes)
*Paracyclops fimbriatus poppei (Rehberg)
Tropocyclops prasinus mexicanus Kiefer
Harpacticoida

Cladocera
*Alona affinis (Leydig)
*A. guttata Sars
*A. quadrangularis (O.F.Müller)
*Alonella sp. Sars
Bosmina longirostris (O.F. Müller)
*Camptocercus rectirostris Schødler
*Ceriodaphnia lacustris Birge
C. quadrangula (O.F. Müller)
Ceriodaphnia spp. Dana
*Chydorus globosus Baird
C. sphaericus (O.F. Müller)
Daphnia galeata mendotae Birge
D. longiremis Sars
*D. pulex Leydig emend. Richard
D. retrocurva Forbes
*D. schødleri Sars
Daphnia spp. O.F. Müller
Diaphanosoma leuchtenbergianum Fischer
Eubosmina coregoni (Baird)
Holopedium gibberum Zaddach
Leptodora kindtii (Focke)
*Leydigia quadrangularis (Leydig)
*Macrothrix laticornis (Jurine)
Polyphemus pediculus (Linné)

---

* Species observed in the Kewaunee area in 1973 that were not reported in 1972.

Table 4.2. Monthly and yearly mean densities and percent composition of zooplankton organisms collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April-November 1973.

Organisms	April[a]		May		June		July	
	#/m^3	% Composition	#/m^3	% Composition	#/m^3	% Composition	#/m^3	% Composition
COPEPODA								
nauplii	1302	14.1	5554	23.2	6574	35.5	750	1.0
calanoid copepodites	17	0.2	1546	6.4	6237	33.6	670	0.9
cyclopoid copepodites	1075	11.7	735	3.1	2301	12.4	2202	3.0
Cyclops bicuspidatus thomasi	2206	24.0	48	0.2	253	1.4	186	0.3
C. vernalis	2	0.0	<1	0.0	1	0.0	2	0.0
Diaptomus spp. (female)	942	10.2	36	0.2	207	1.1	117	0.2
D. ashlandi (male)	577	6.3	6	0.0	95	0.5	27	0.0
D. minutus (male)	103	1.1	12	0.1	8	0.0	129	0.2
D. oregonensis (male)	66	0.7	2	0.0	1	0.0	8	0.0
D. sicilis (male)	44	0.5	0	0.0	<1	0.0	8	0.0
D. siciloides (male)	2	0.0	0	0.0	0	0.0	0	0.0
Epischura lacustris	0	0.0	0	0.0	0	0.0	10	0.0
Eucyclops agilis	0	0.0	0	0.0	<1	0.0	0	0.0
Eurytemora affinis	0	0.0	1	0.0	<1	0.0	6	0.0
Limnocalanus macrurus	2	0.0	0	0.0	1	0.0	0	0.0
Mesocyclops edax	0	0.0	0	0.0	0	0.0	18	0.0
Paracyclops fimbriatus poppei	0	0.0	<1	0.0	0	0.0	2	0.0
Tropocyclops prasinus mexicanus	55	0.6	60	0.3	<1	0.0	89	0.1
Total Adult Copepoda	3999	43.4	165	0.7	566	3.1	602	0.8
Total Copepoda[b]	6410	69.6	8002	33.4	15679	84.6	4220	5.8
CLADOCERA								
Alona affinis	0	0.0	0	0.0	0	0.0	0	0.0
A. guttata	0	0.0	<1	0.0	0	0.0	0	0.0
A. quadrangularis	0	0.0	0	0.0	0	0.0	0	0.0
Alonella sp.	0	0.0	0	0.0	0	0.0	0	0.0
Bosmina longirostris	23	0.2	271	1.1	722	3.9	51520	70.6
Ceriodaphnia lacustris	0	0.0	0	0.0	0	0.0	0	0.0
C. quadrangula	0	0.0	0	0.0	<1	0.0	0	0.0
Ceriodaphnia spp.	0	0.0	0	0.0	0	0.0	2	0.0
Chydorus globosus	0	0.0	0	0.0	0	0.0	0	0.0
C. sphaericus	6	0.1	1	0.0	3	0.0	7	0.0
Daphnia galeata mendotae	29	0.3	3	0.0	1	0.0	487	0.7
D. longiremis	166	1.8	7	0.0	162	0.9	69	0.1
D. pulex	1	0.0	0	0.0	0	0.0	0	0.0
D. retrocurva	0	0.0	0	0.0	1	0.0	419	0.6
D. schødleri		0.0	0	0.0	0	0.0	0	0.0
Daphnia spp.	2	0.0	0	0.0	1	0.0	0	0.0
Diaphanosoma leuchtenberglanum	0	0.0	0	0.0	0	0.0	0	0.0
Eubosmina coregoni	63	0.7	20	0.1	19	0.1	166	0.2
Holopedium gibberum	0	0.0	<1	0.0	0	0.0	111	0.2
Leptodora kindtii	0	0.0	<1	0.0	0	0.0	0	0.0
Leydigia quadrangularis	0	0.0	0	0.0	0	0.0	0	0.0
Macrothrix laticornis	0	0.0	0	0.0	0	0.0	0	0.0
Polyphemus pediculus	0	0.0	0	0.0	0	0.0	399	0.5
Total Cladocera	290	3.1	302	1.3	910	4.9	53183	72.8
Total Rotifera	2510	27.3	15678	65.4	1946	10.5	15619	21.4
Total Zooplankton	9211		23983		18536		73021	

Table 4.2. Continued.

Organisms	August		September		October		November		1973	
	#/m^3	% Composition	#/m^3	% Composition	#/m^3	% Composition	#/m^3	% Composition	Mean #/m^3	% of total zooplankton
COPEPODA										
nauplii	1185	1.9	1254	2.5	757	4.8	410	0.1	2223	6.1
calanoid copepodites	9656	15.8	9057	18.0	1991	12.6	4593	11.1	4221	11.5
cyclopoid copepodites	20995	34.4	17478	34.8	4211	26.7	24289	58.8	9161	25.0
Cyclops bicuspidatus thomasi	3177	5.2	1712	3.4	186	1.2	1306	3.2	1134	3.1
C. vernalis	1	0.0	59	0.1	41	0.3	35	0.1	18	0.0
Diaptomus spp. (female)	668	1.1	354	0.7	29	0.2	549	1.3	363	1.0
D. ashlandi (male)	596	1.0	189	0.4	7	0.0	176	4.3	209	0.6
D. minutus (male)	27	0.0	57	0.1	<1	0.0	231	0.6	68	0.2
D. oregonensis (male)	129	0.2	40	0.1	5	0.0	334	0.8	73	0.2
D. sicilis (male)	0	0.0	0	0.0	1	0.0	13	0.0	9	0.0
D. siciloides (male)	0	0.0	0	0.0	0	0.0	0	0.0	<1	0.0
Epischura lacustris	7	0.0	31	0.1	23	0.1	58	0.1	16	0.0
Eucyclops agilis	1	0.0	4	0.0	<1	0.0	1	0.0	1	0.0
Eurytemora affinis	1	0.0	4	0.0	1	0.0	5	0.0	2	0.0
Limnocalanus macrurus	0	0.0	<1	0.0	0	0.0	0	0.0	<1	0.0
Mesocyclops edax	335	0.5	118	0.2	24	0.2	4	0.0	62	0.2
Paracyclops fimbriatus poppei	0	0.0	0	0.0	0	0.0	0	0.0	<1	0.0
Tropocyclops prasinus mexicanus	2577	4.2	1761	3.5	442	2.8	1215	3.0	775	2.1
Total Adult Copepoda	7519	12.3	4329	8.6	759	4.8	3924	9.5	2730	7.5
Total Copepoda[b]	39358	64.4	32125	64.0	7718	48.9	33213	80.4	18342	50.1
CLADOCERA										
Alona affinis	1	0.0	3	0.0	0	0.0	0	0.0	<1	0.0
A. guttata	0	0.0	1	0.0	0	0.0	0	0.0	<1	0.0
A. quadrangularis	0	0.0	0	0.0		0.0	1	0.0	<1	0.0
Alonella sp.	0	0.0	0	0.0	1	0.0	0	0.0	<1	0.0
Bosmina longirostris	11563	18.9	5691	11.3	6210	39.3	5432	13.2	10178	27.8
Ceriodaphnia lacustris	43	0.1	4	0.0	0	0.0	0	0.0	6	0.0
C. quadrangula	30	0.0	48	0.1	1	0.0	0	0.0	10	0.0
Ceriodaphnia spp.	28	0.0	0	0.0	0	0.0	0	0.0	4	0.0
Chydorus globosus	0	0.0	0	0.0	0	0.0	1	0.0	<1	0.0
C. sphaericus	239	0.4	663	1.3	24	0.2	9	0.0	119	0.3
Daphnia galeata mendotae	490	0.8	712	1.4	50	0.3	468	1.1	282	0.8
D. longiremis	1581	2.6	40	0.1	1	0.0	3	0.0	254	0.7
D. pulex	0	0.0	0	0.0	0	0.0	0	0.0	<1	0.0
D. retrocurva	3638	6.0	4783	9.5	1186	7.5	909	2.2	1367	3.7
D. schødleri	0	0.0	0	0.0	0	0.0	0	0.0	<1	0.0
Daphnia spp.	0	0.0	0	0.0	0	0.0	0	0.0	<1	0.0
Diaphanosoma leuchtenbergianum	0	0.0	7	0.0	1	0.0	0	0.0	1	0.0
Eubosmina coregoni	699	1.1	3167	6.3	242	1.5	642	1.6	627	1.7
Holopedium gibberum	229	0.4	421	0.8	8	0.1	6	0.0	98	0.3
Leptodora kindtii	20	0.0	11	0.0	<1	0.0	3	0.0	4	0.0
Leydigia quadrangularis	0	0.0	0	0.0	0	0.0	1	0.0	<1	0.0
Macrothrix laticornis	0	0.0	3	0.0	<1	0.0	0	0.0	1	0.0
Polyphemus pediculus	0	0.0	0	0.0	0	0.0	0	0.0	50	0.1
Total Cladocera	18564	30.4	15556	31.0	7721	48.9	7466	18.1	13000	35.5
Total Rotifera	3195	5.2	3532	7.0	344	2.2	630	1.5	5294	14.4
Total Zooplankton	61117		50213		15783		41305		36646	

[a] Transects II, III, and IV.
[b] Includes Harpacticoida.

(Brooks 1957). The Great Lakes usually do not provide suitable habitat for this species, although it has been reported from extreme western Lake Erie (Davis 1969) and from southern Green Bay (Gannon 1972). In the present study, Daphnia pulex and Diaptomus siciloides were found only in April.

Eucyclops agilis and Ergasilus chautauquaensis are copepods that were not observed in the 1971 or 1972 preoperational studies (Industrial BIO-TEST Laboratories, Inc. 1972a and 1973). Eucyclops agilis is a littoral species which has been previously reported in other Lake Michigan studies (Gannon 1972; Industrial BIO-TEST Laboratories, Inc. 1972b). All Ergasilus species except E. chautauquaensis have been found as parasites in the gill arches of fish (Roberts 1970). Ergasilus chautauquaensis was rare in samples from the study area.

Cladoceran species other than Daphnia pulex which were observed in 1973, but not in 1972, included Alona affinis, A. guttata, A. quadrangularis, Alonella sp., Camptocercus rectirostris, Ceriodaphnia lacustris, Chydorus globosus, Daphnia schødleri, Leydigia quadrangularis, and Macrothrix laticornis. All of these were collected in insignificant numbers and all but D. schødleri and C. lacustris are littoral or epibenthic organisms.

Three Cladocera not seen in 1973, but encountered in 1972, were Chydorus latus, Eurycercus lamellatus and Scapholeberis sp. These tychoplankters are usually vegetation or bottom dwellers in the littoral zone and their infrequent appearance in the plankton near KNPP probably has no ecological significance.

B. Seasonal and Spatial Occurrences of Major Zooplankton Groups

A wide variety of limnological and meteorological phenomena may affect zooplankton populations in the littoral zone of Lake Michigan. Some of these environmental factors include subsurface currents, thermal barriers, the nature and intensity of light, and upwellings. Any one of these factors may disperse or concentrate plankton populations on an hourly, daily, or seasonal basis. This fact was manifest in the 1972 preoperational study at KNPP when copepod and cladoceran populations were doubled and even tripled within a time span of only three days, resulting in many statistically significant differences in populations between sampling periods. Although such short-term fluctuations were not detectable with the monthly sampling design employed in 1973, they undoubtedly contributed appreciably to the temporal and spatial differences noted in the following discussion for the major taxa.

A summary of the statistical evaluation of data for total zooplankton and the major taxa is presented in Table 4.3. The two statistical procedures used to test the data yielded similar results. Some patterns among the sampling locations were noted. Such patterns will be pointed out in the following sections of the report as they apply to the major zooplankton groups or species.

1. Total Zooplankton

Total zooplankton populations increased from an April mean of 9200 organisms/m^3 to a yearly maximum of 73000/m^3 in July (Table 4.2). Numbers of zooplankton declined slightly in August and September, but mean densities remained above 50000/m^3. The mean density of the zooplankton

Table 4.3. Monthly summary of Tukey's Multiple Comparison Tests on abundance of major groups of zooplankton collected in Lake Michigan near Kewaunee Nuclear Power Plant, April-November 1973.

Organism	Depth (Meters)	Sampling Date			
		13 April[a]	26 May	26 June	24 July
Total Zooplankton	3	II, III > IV	I > III	II, III > I, V	I > II > III, IV, V
	6	II, III > IV	I, IV V, II > III	V, III, IV, II > I	II > V, IV
	9	IV > II > III	-	V > II, III > I; V > IV	II > V, I
Total Crustaces	3	II > IV	I > III, IV	II, III, IV > I, V	I > II > III, IV, V
	6	II, III > IV	I > III, IV, II, V; V > III	V, III, IV, II > I	II > V, IV
	9	IV > II > III	IV, V > II, I > III	V > IV > II, III > I	II > IV > I, V, II > III
Total Copepoda	3	II > IV	I > III, IV	II, III, IV > V, I	I > IV, V, II, III; III > IV
	6	II, III > IV	I > IV, II > III; I > V	V, III, IV, II > I	III > IV, V
	9	IV > II > III	IV, V > I, II > III	V > IV > II, III > I	I, II > V, III, IV
Nauplii	3	-[b]	I > IV, III	II, III, IV > I V	I > V
	6	-	I > II, IV, V > III	V, I, III, II, IV	n. s.[c]
	9	IV, II > III	IV, V > I, II > III	V > IV > I, II, III > I	I, II > III, IV; I > V
Calanoid Copepodites	3	-	V, II, IV, I > III	II > V, I; III, IV > V	n. s.
	6	-	V > IV, II > III; I > III	III, V, IV, II > I	III > IV, II, V, I
	9	-	IV > V ≯ II > I > III	V > IV > I, II; V > III, II > I	I > III, V
Cyclopoid Copepodites	3	-	I > II, III, IV, V	II, III, I, IV > V	I > III > IV, V; I > II
	6	II, III > IV	I > II, IV V > III	II, III, IV, V > I; III > IV	III > IV, V; I > IV
	9	IV > II > III	I > V, II > III; I > IV	V > IV > I, II, III; II > I	n. s.
<u>Cyclops bicuspidatus thomasi</u>	3	-	-	-	-
	6	III, II > IV	-	-	-
	9	IV > II, III	-	-	-
<u>Diaptomus</u> spp. (female)	3	II > III > IV	-	-	-
	6	II, III > IV	-	V, III, II > I; V > IV	-
	9	IV > II, III	-	V > III	-
<u>Diaptomus ashland</u>: (male)	3	III, II > IV	-	-	-
	6	III, II > IV	-	III, V, II, IV > I	-
	9	IV > III, II	-	-	-

Table 4.3. Continued.

Organism	Depth (Meters)	Sampling Date 13 April[a]	26 May	26 June	24 July
Tropocyclops prasinus mexicanus	3	-	-	-	-
	6	-	-	-	-
	9	-	-	-	-
Total Cladocera	3	-	II > III, IV, V	III, II > V	I > II > III, IV, V
	6	-	I, II > III, IV, V; V > III	III, II, IV, V > I	II > IV, V
	9	-	I > III, V	-	II > III, IV > I; II, IV > V
Bosmina longirostris	3	-	II > III, IV, V	II, III > V	I > II > III, IV, V
	6	-	II, I > V > III; II, I > IV	III, II, IV > I	II > IV, V
	9	-		n. s.	II > III, IV > I; II, IV > V
Daphnia galeata mendotae	3	-	-	-	-
	6	-	-	-	-
	9	-	-	-	-
Daphnia retrocurva	3	-	-	-	-
	6	-	-	-	-
	9	-	-	-	-
Total Rotifera	3	II, III > IV	n. s.	III, II > I	n. s.
	6	-	IV, I, V, II > III	V, III, IV, II > I	II, III > I, IV; II > V
	9	II > IV	I, III > V, IV, II	II, III > IV	n. s.

Table 4. 3. Continued.

Organism	Depth (Meters)	Sampling Date 28 August	26 September	23 October	13 November
Total Zooplankton	3	II, III > I > IV, V	V, II > I, III, IV	V > III > IV, I; V > II	V > I, II, III, IV
	6	II > I, IV, V	n. s.	II, III, IV, V > I	V > I > II, III, IV; II > III
	9	V > II, III, IV	n. s.	I, II, III, V > IV	III, I > II > IV
Total Crustacea	3	II, III > I > IV, V	V, II > I, III, IV	V > III < IV, I; V > II	V > I, II, III; IV > III
	6	II > I, IV, V	n. s.	II, III, IV, V > I	V > I > II, III; IV; II > III
	9	V > II, III, IV	n. s.	I, III, V > IV	II, III, V > I, IV
Total Copepoda	3	II > III, I > IV, V	II, V > I, III, IV	V > II, III > IV, I	n. s.
	6	II > I, IV	II > I, III, IV, V	V, II, IV, III > I	V, I > II, III, IV; II > III
	9	V > III, II	n. s.	V, III > IV, II	II, III > I, IV; V > IV
Nauplii	3	II, III > I, IV, V	n. s.	II > I, III, IV, V	n. s.
	6	n. s.	n. s.	II > I	n. s.
	9	n. s.	n. s.	n. s.	n. s.
Calanoid Copepodites	3	II, I > III, IV, V; III > V	IV > I, II, III; V > I	II > I > III > IV; V > IV, III	I > II, III, IV, V; II, V > IV
	6	II > V	II > III, IV > I; II > V	IV, II > I, III; V > I	V, I > III, IV; V > II
	9	n. s.	II, V > I, III	V > I, III > II, IV	III, V > II, I
Cyclopoid Copepodities	3	II > III > I > IV, V	II > III, V > IV; II > I	V > II, III > I, IV	n. s.
	6	n. s.	II, I > V; II > III	V > I, IV; II, III > I	V > II, III, IV; II > III
	9	V > III, II, I	n. s.	V > II, IV	II, III > IV, I; V > IV
Cyclops bicuspidatus thomasi	3	III, II, I > V, IV	V > I, III; IV > I	V > I, IV	n. s.
	6	II > V, IV, I	n. s.	II, IV, V > I	V > I, II, III, IV
	9	V > I, II, III, IV	n. s.	n. s.	III > I, IV, V; II, V > IV
Diaptomus spp. (female)	3	I, II > III, IV > V	II, IV, V > I; IV > III	-	I > II, IV, V
	6	n. s.	II > I	-	I > II, III, IV; V > III
	9	n. s.	-	-	n. s.
Diaptomus ashland: (male)	3	I, II, IV > V; I > III	n. s.	-	n. s.
	6	I > IV	n. s.	-	n. s.
	9	n. s.	n. s.	-	n. s.
Tropocyclops prasinus mexicanus	3	n. s.	V > I > IV, II; V > III > IV	II, III > I, IV; V > I	IV > I, II, III, V ; V > I
	6	II, III, IV, V > I; II > III	n. s.	IV > I, III; V > I	V > II, III, IV; I, II > III
	9	V > III, II	V > I, II, III, IV	III > II, IV, I, V	n. s.
Total Cladocera	3	II, III > I, IV, V	V > I, II, III, IV	V > I, IV, II, III	V > IV > I, II, III
	6	II > I, V	V > II, III	II, III, IV, V > I	V > I, II, III, IV; IV > III
	9	V, I > II, III, IV	IV > II, I; V > II	II > III, IV, V; I > IV, III > IV	V > III > I, II, IV; II > IV

Table 4.3. Continued.

Organism	Depth (Meters)	Sampling Date 28 August	26 September	23 October	13 November
Bosmina longirostris	3	II, III > I, IV, V	V > I	V > I, II, III, IV; III > I	V > IV > I, II, III
	6	II > III, V > I; IV > I	IV > III	II, III, IV, V > I	V > IV > I, II, III
	9	V, I > II; V > III	V > II, III	II > III > IV > I, V	V > III > I, IV; V > II > IV
Daphnia galeata mendotae	3	n. s.	V > I, II, III, IV	V > I, II, III, IV	V > I, III, IV
	6	III > V	V, II > I	n. s.	V > I, II, III, IV
	9	n. s.	n. s.	n. s.	III > II, IV
Daphnia retrocurva	3	I, II > III > IV, V	V > I, II, III, IV	I > II, III, IV, V	n. s.
	6	I, II > V; I > IV	V > II, III, IV; I > II	n. s.	n. s.
	9	I, V > III, IV; II > IV	IV > II	I > II, V > IV; I 2 III	III > I, II, IV; V > I, IV
Total Rotifera	3	II, III, IV, V > I	n. s.	III, V > II, IV > I	IV > I, II, III, V
	6	II > I, III; IV > I	III, V > I, II, IV	III, IV > I	II > III, IV
	9	n. s.	n. s.	n. s.	n. s.

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[a] No samples collected from Transects I and V in April.

[c] Results of test not significant

[b] Abundance of taxa too low to apply to test.

declined to 16000/m^3 in October, but more than doubled by the November sampling. The lower density which occurred in October was also noted for the phytoplankton assemblage (Chapter 3, Figure 3.1). The only data which did not reflect this general minimum were those gathered inshore for the Cladocera (Figure 4.1) and the inshore Cyanophyta (Chapter 3).

Total zooplankton populations at inshore (10 ft), middle (20 ft), and offshore (30 ft) locations showed similar fluctuations, except in June, September and October (Figure 4.2). Larger populations occurred offshore in June and inshore in September, as a result of pulses of immature copepods (Figure 4.3). A similar pulse occurred for the Cladocera at the inshore locations in October (Figure 4.1).

2. Total Copepoda

Only 15% of the Copepoda collected throughout the year were adults (Table 4.2) with the remainder consisting of 50% cyclopoid copepodites, 23% calanoid copepodites, and 12% nauplii. The number of nauplii may, however, have been underestimated due to the fact that the very early instars are smaller than the aperture of the #12 mesh net used for sampling.

Copepods increased from an April mean of 6400 organisms/m^3 to a spring peak of 16000/m^3 in June (Table 4.2). Mean numbers then declined to the year minimum of 4200/m^3 in July before increasing dramatically to the yearly maximum of 39000/m^3 in August. Populations continued to fluctuate throughout the fall, being abundant in September (32000/m^3), relatively sparse in October (7700/m^3), and very abundant again in November (33000/m^3).

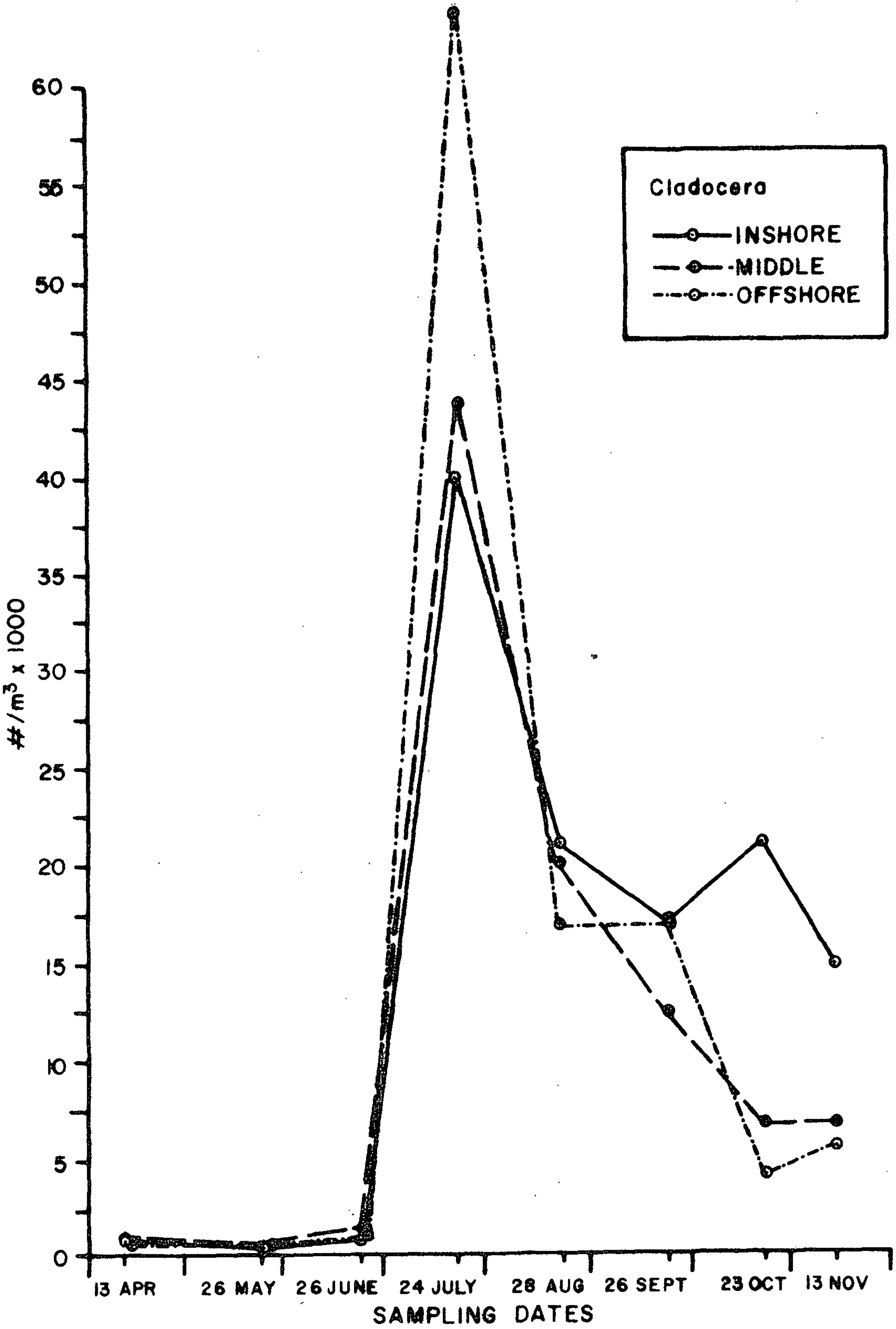

Figure 4.1. Mean densities of total Cladocera collected at three distances from shore in Lake Michigan near the Kewaunee Nuclear Powe Plant, April-November 1973.

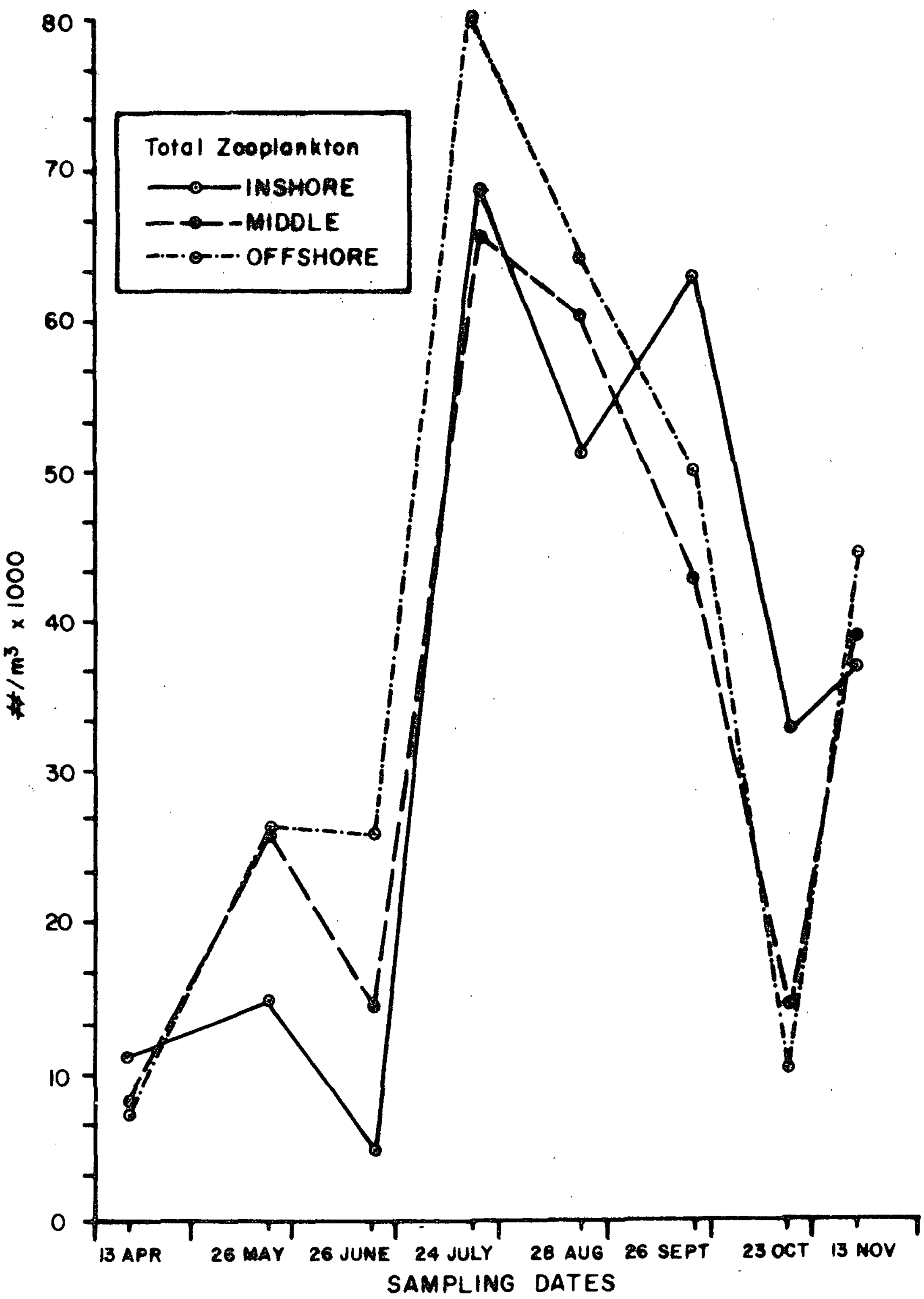

Figure 4.2. Mean densities of total zooplankton collected at three distanc from shore in Lake Michigan near the Kewaunee Nuclear Pow Plant, April-November 1973.

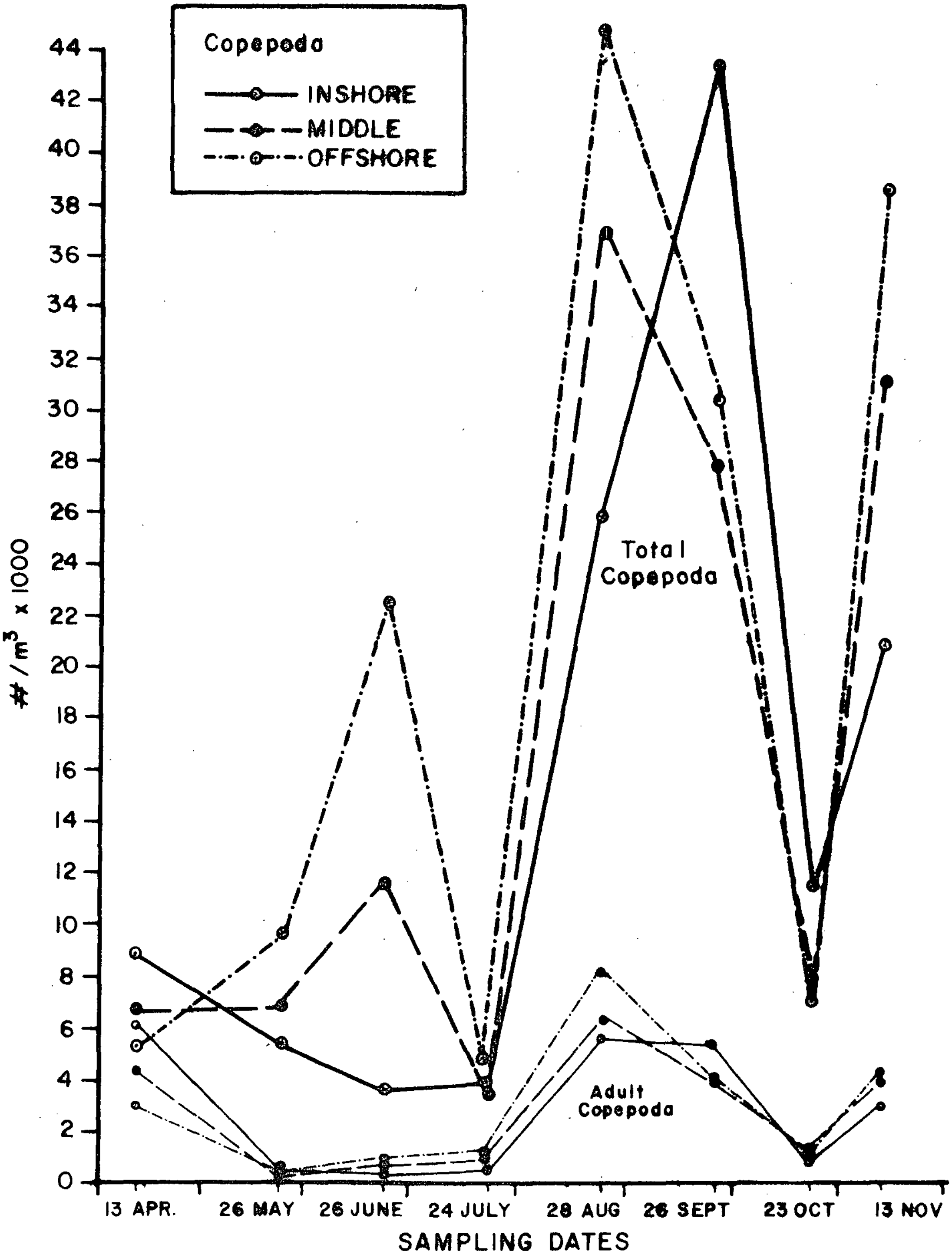

Figure 4.3. Mean densities of total Copepoda and adult Copepoda collected at three distances from shore in Lake Michigan near the Kewaunee Nuclear Power Plant, April-November 1973.

If sampling had continued through the winter, the relative importance of Copepoda would have probably been greater. Other studies of Lake Michigan indicate that in both littoral and pelagic situations, winter populations of planktonic Crustacea consist largely of Copepoda, particularly Cyclops bicuspidatus thomasi and Diaptomus spp. (Industrial BIO-TEST Laboratories, Inc. 1972b, 1974a, 1974b; Gannon 1972; Hunt and Barbour 1974).

Total copepod populations at the three depth contours showed similar fluctuations during all months except May, June and September (Figure 4.3). The inshore populations in May decreased appreciably from April levels, primarily due to a large drop in numbers of adults; however, the offshore populations rose during the same time span due to an increase in numbers of immature copepods. The disparity between inshore and offshore populations in June was again due to a considerable increase in the number of calanoid copepodites at the offshore and middle locations as opposed to the inshore locations. This trend was apparent for all transects except Transect I (Figure 4.4) where numbers were similar at all locations. The opposite situation existed in September with inshore populations being much larger than those offshore. This high abundance inshore was primarily due to increased numbers of cyclopoid copepodites in all transects and resulted in the largest inshore densities of the year for total Copepoda (43000/m^3).

a. Calanoid Copepodites

Calanoid copepodites increased from a very low mean density in April (17 organisms/m^3) to a spring peak in June (6200/m^3) (Figure 4.4).

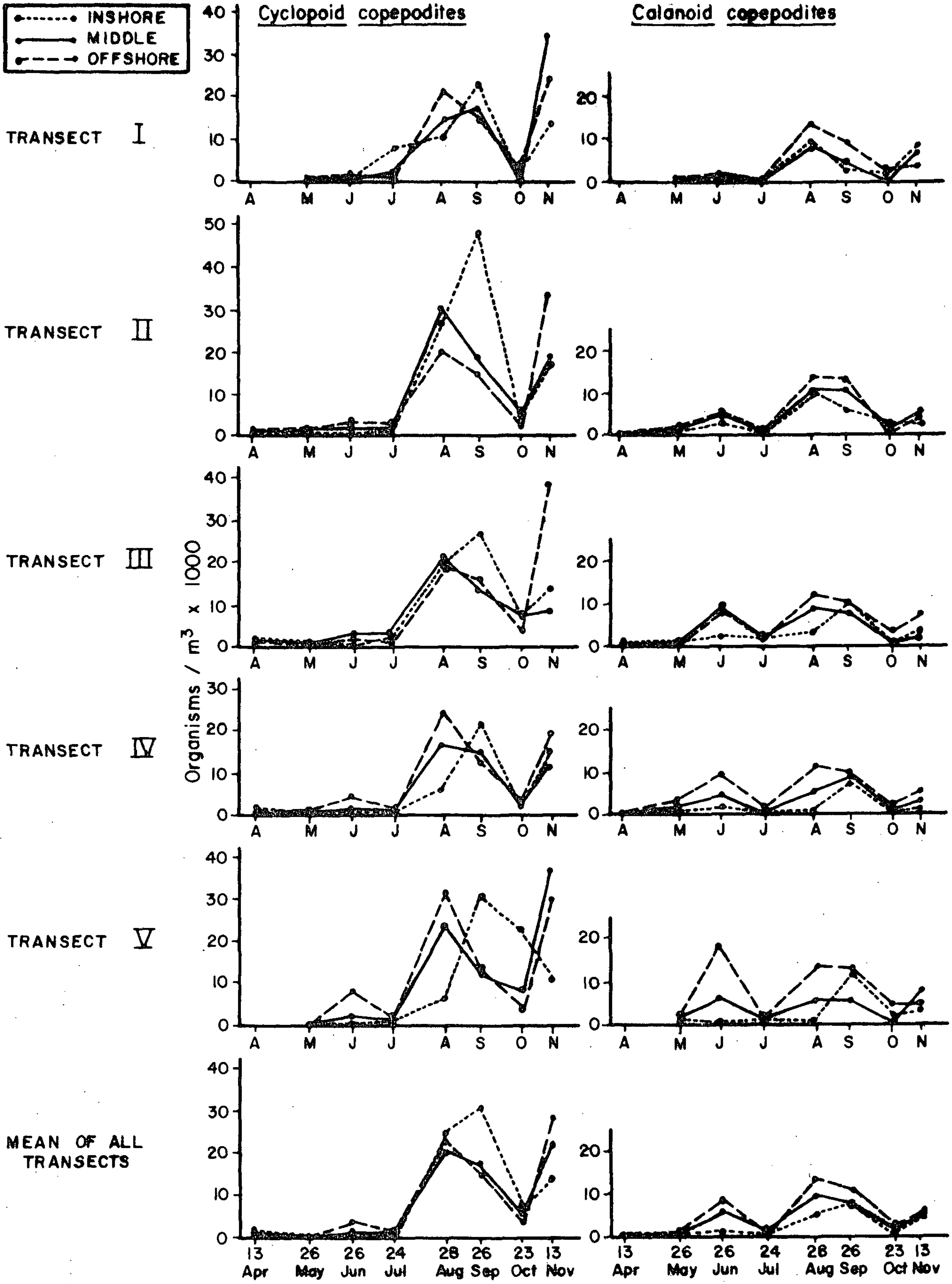

Figure 4.4. Location densities and mean densities of calanoid and cyclopoid copepodites collected along five transects in Lake Michigan near the Kewaunee Nuclear Power Plant, April-November 1973.

They declined sharply in July (670/m^3) followed by the yearly maximum in August (9700/m^3). Populations remained high in September (9100/m^3) and then dropped sharply again in October (2000/m^3) before doubling in November (4500/m^3).

Dissimilar trends among calanoid copepodites at inshore, middle, and offshore locations (Figure 4.4) were noted in the months of June (Transect V), August (Transect V), September (Transects II, III, and IV), and October (Transect II). The offshore assemblage of calanoid copepodites attained an early peak in June, reaching the yearly maximum of more than 19000 individuals/m^3 at Location 22 (Transect V). Numbers at the inshore locations during this period had declined slightly from the previous month. Statistical evaluation of these data revealed that the standing crop of calanoid copepodites along Transect V was significantly lower at the inshore location than inshore locations along other transects, and significantly higher at the offshore location than at other offshore locations.

The June data for calanoid copepodites are an example of consistent results for zooplankton collected in 1973. This consistency is that most of the taxa were higher in number in samples from offshore locations in the non-winter months. In every collection period except April, the mean density of calanoid copepodites was greater offshore than at the inshore or the middle locations (Figure 4.4), with only five exceptions to this trend: Transect III in June (middle location higher than offshore); Transect II in October (offshore density lowest); Transect V in October (middle location higher than offshore);

and Transects I and V in November (middle locations higher than offshore).

The August assemblage of calanoid copepodites exhibited upward trends at all sampling locations, except at the inshore location of Transect V. The mean numbers from the middle and offshore locations reflected the observed yearly maximum of calanoid copepodites at those depth contours. The yearly inshore maximum of calanoid copepodites occurred in September in Transects III, IV, and V, but numbers in Transects I and II declined from the previous month. Since the August and September densities at the offshore locations were nearly equal, a higher maximum probably occurred sometime between sampling periods.

b. Cyclopoid Copepodites

Low numbers of cyclopoid copepodites were present from April through July (Figure 4.4). In August the assemblages at the offshore and middle locations attained maximum density. At the offshore localities of all five transects, the cyclopoid copepodites ranged from 18000 to 32000 individuals/m^3, while at the middle locations the August maxima ranged from 15000 to 30000 individuals/m^3.

Cyclopoid copepodites at the inshore locations did not attain a maximum until September, at which time they ranged from 21000 to 48000 individuals/m^3. A general reduction in numbers occurred in October at all locations except the inshore one in Transect V. The November pulse in cyclopoid copepodites was the yearly maximum number observed in some instances (Locations 3, 4, 8, 13 and 21) all of which were either middle or offshore locations.

3. Total Cladocera

Cladoceran numbers were very low until July when the yearly maximum for inshore (39000/m^3), middle (43000/m^3), and offshore 64000/m^3) populations occurred (Figure 4.1). After July, numbers varied among the locations along the three depth contours. Inshore populations declined from July to September but increased in October. Populations at middle locations declined through October while offshore populations dropped sharply in August and then leveled off in September. There was another sharp decline in numbers of offshore Cladocera in October followed by a slight increase in November.

4. Rotifera

Population of those rotifers retained by a #12 mesh net fluctuated considerably, with the largest pulse occurring at the inshore localities between June and July (from 820 organisms/m^3 to 25000/m^3) (Figure 4.5). Populations in the middle localities displayed two similar maxima in May and July. After the July maximum, rotifers represented less than 10% of the total zooplankton (Table 4.2). Mean densities of less than 1000/m^3 were observed in October and November.

C. Spatial and Seasonal Dynamics of Major Species

1. Cyclops bicuspidatus thomasi

The most abundant adult copepod collected in the area of the KNPP was Cyclops bicuspidatus thomasi. Its numbers were relatively high in April (1200 to 4600 individuals/m^3), particularly at the inshore localities where the

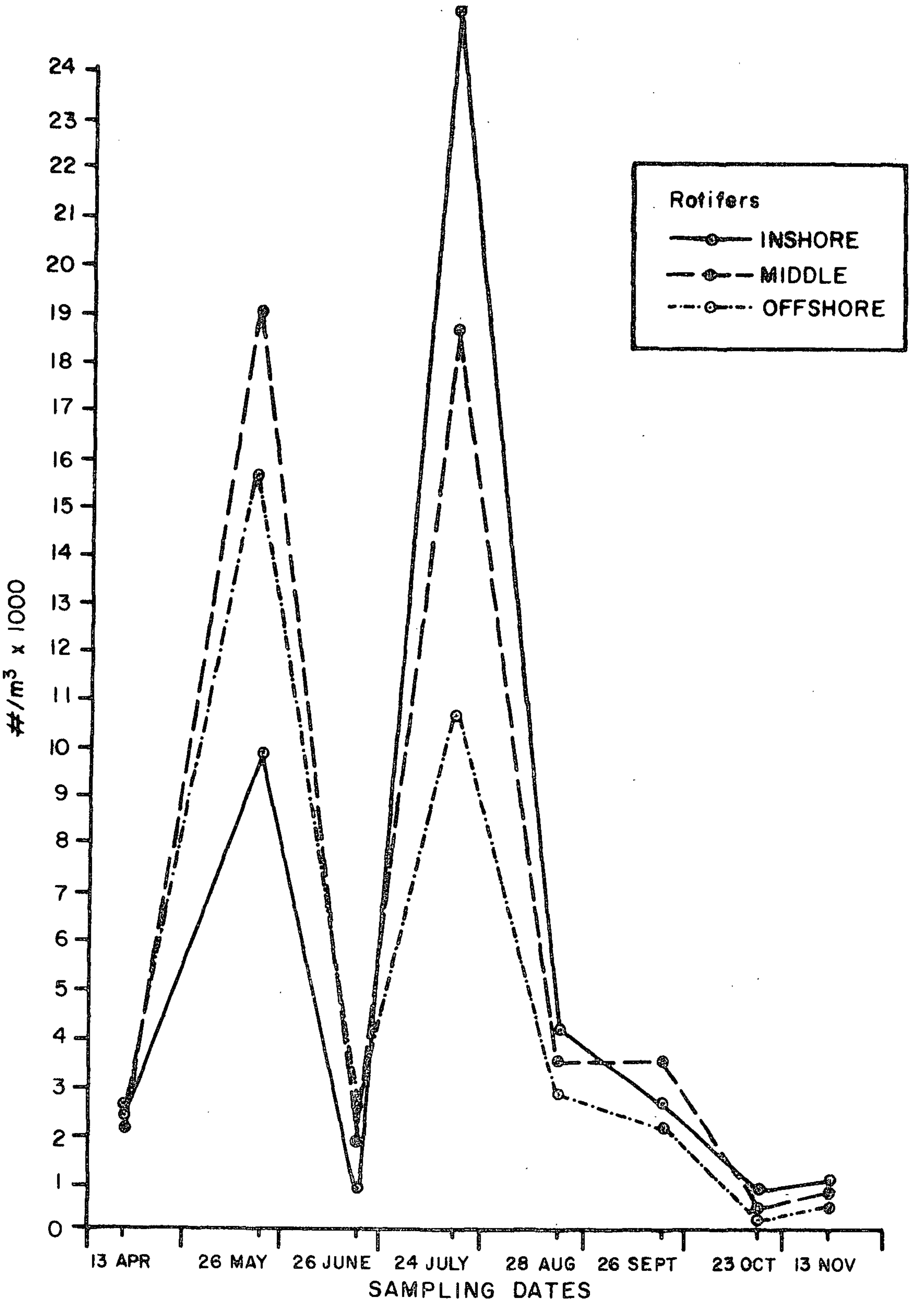

Figure 4.5. Mean densities of total Rotifera collected at three distances from shore in Lake Michigan near the Kewaunee Nuclear Power Plant, April-November 1973.

yearly maximum for these locations occurred (Figure 4.6). The density of C. bicuspidatus thomasi adults decreased considerably in May and remained low through July. At both middle and offshore locations the yearly maximum number of individuals was attained in August along all five transects. The highest number at a middle location was 5000 organisms/m^3 (Transect II); and at an offshore location, 6800/m^3 (Transect V). Peaks at the inshore locations occurred in August at Transects I, II and III, but not until September at Transects IV and V. Numbers declined to a second minimum in October, but increased again in November. The population of C. bicuspidatus thomasi in November was eight times larger than the previous month. The seasonal pattern for this species resembled that described by other investigators (Andrews 1953; Schindler and Noven 1971; Industrial BIO-TEST Laboratories, Inc. 1972b, 1974a, 1974b; Hunt and Barbour 1974).

Cyclops bicuspidatus thomasi is predacious and specimens preserved while devouring Diaptomus copepodites were frequently collected. In Marion Lake, British Columbia, a study conducted by McQueen (1969) showed that C. bicuspidatus thomasi consumed approximately 30% of the Cyclops and Diaptomus nauplii.

2. Tropocyclops prasinus mexicanus

The population of the warm-water stenotherm (Rylov 1948), Tropocyclops prasinus mexicanus, was very low until August, when the yearly maximum was observed along every transect except Transect I (Figure 4.6). The largest mean density of this species (5800 individuals/m^3) occurred in

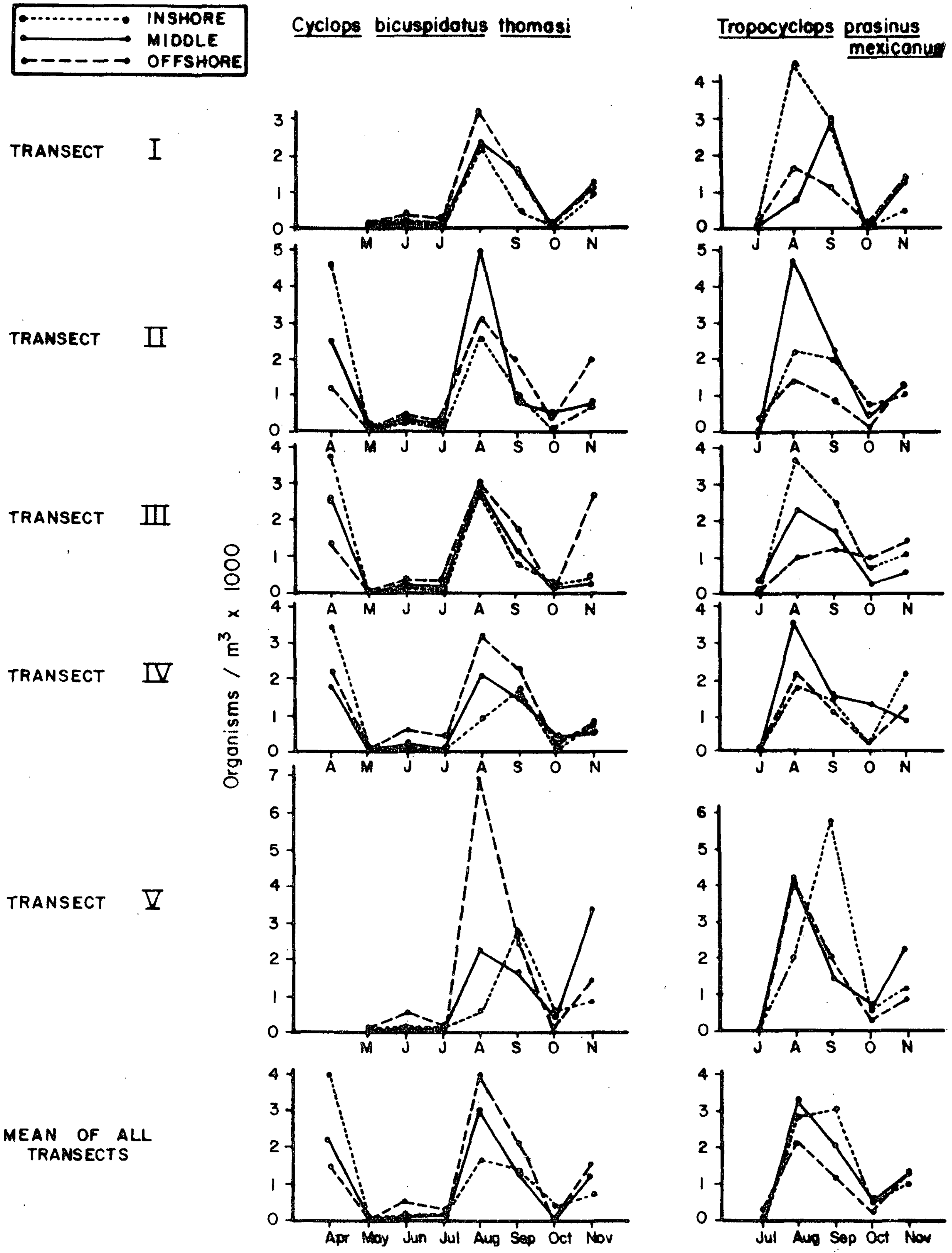

Figure 4.6. Location densities and mean densities of Cyclops bicuspidatus thomasi and Tropocyclops prasinus mexicanus collected along five transects in Lake Michigan near the Kewaunee Nuclear Power Plant, April-November 1973.

September at Location 20. In October, the population of T. prasinus mexicanus adults showed a fall minimum, except for the gradual decrease observed at the middle location in Transect IV. The population at that location was found to be significantly greater than populations at middle locations in Transects I and III. The population in November was more than double that of the previous month (Table 4.2) reflecting the general increase of zooplankton in late fall.

As stated by Schindler and Novén (1971), not enough is known concerning the seasonal dynamics of this species to say whether the observed seasonal pattern is typical.

3. Diaptomus spp.

The counts for Diaptomus spp. during this study were low relative to other abundant Copepoda (Figure 4.7). When the first samples were collected in April, the numbers ranged from 730 to 2800/m^3 at the various sampling locations. After April, the numbers at the inshore and middle locations remained quite low. The populations were slightly more numerous at the offshore locations where the mean density increased in June and August. After a minimum in October, the numbers increased 27-fold in November (Table 4.2).

Statistical differences in the number of Diaptomus spp. between locations were numerous in April (Table 4.3). Diaptomus spp. (female) were different at the inshore and middle localities with the population at Transect II being significantly greater than that at Transect IV. The offshore location in Transect IV contained significantly greater numbers of Diaptomus spp. (female) than those at the offshore location of Transect II. The same type of reversal

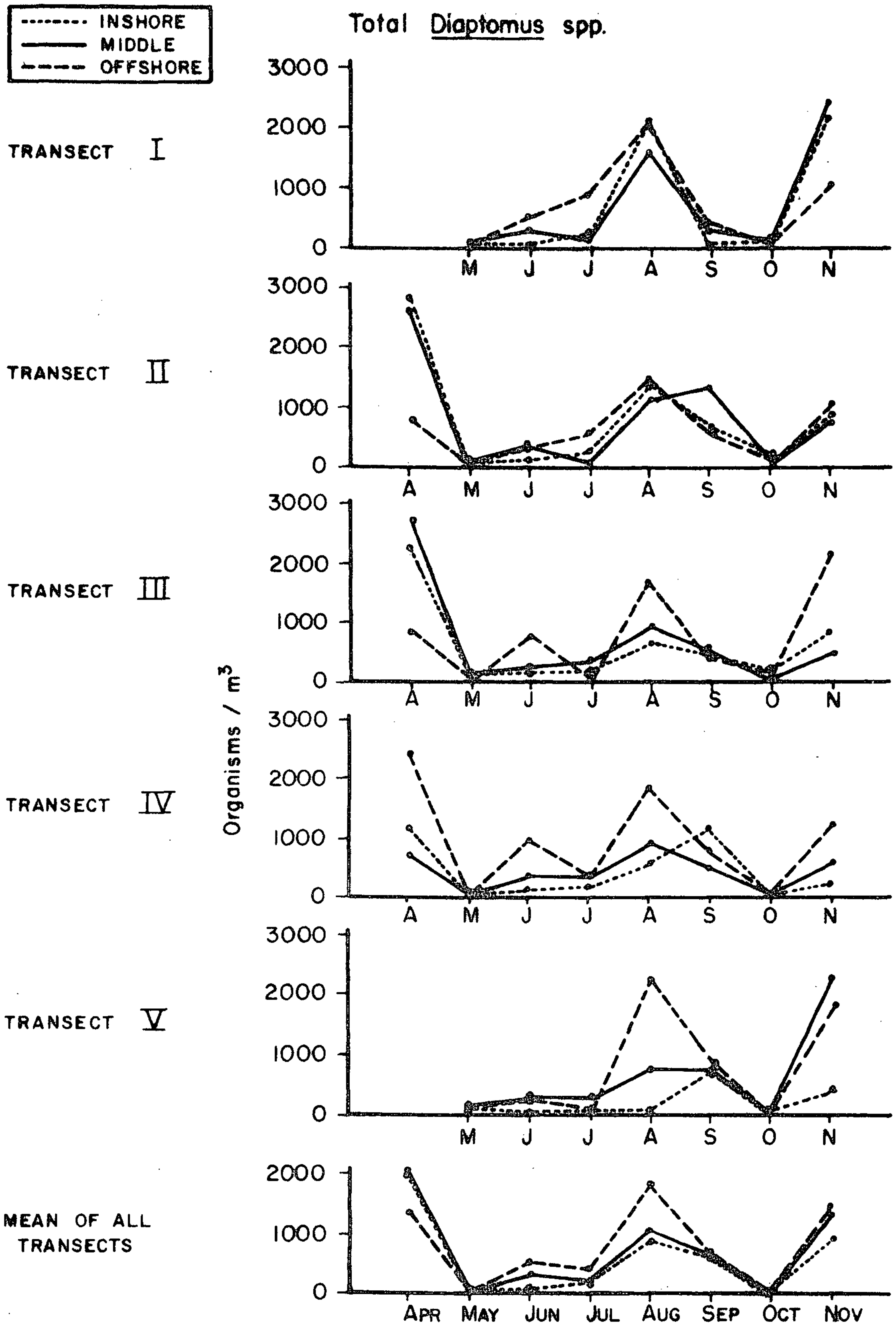

Figure 4.7. Location densities and mean densities of Diaptomus spp. collected along five transects in Lake Michigan near the Kewaunee Nuclear Power Plant, April-November 1973.

occurred with Diaptomus ashlandi (male). Other significant differences between Transects IV and II occurred offshore among standing crops of Diaptomus minutus (male) and inshore among D. sicilis (male).

4. Bosmina longirostris

The cladoceran, Bosmina longirostris, numerically dominated the microcrustacea in the warmer months. The very low numbers observed in June were followed by the yearly maximum in July (Figure 4.8). The mean population density at the 30-ft locations in July was much higher than that of the 20- or 10-ft locations. Location 8 had the most numerous population with 93000 individuals/m^3 followed by 66000 and 64000/m^3 at Locations 17 and 13, respectively. Only in Transect I did the July inshore maximum exceed the offshore populations with 67000 individuals/m^3 at Location 2. The population after July decreased at all locations except Location 11 (inshore location, Transect III) where the yearly maximum was attained in August (33000/m^3). Data from Location 20 did not exhibit a yearly maximum until October (56000 organisms/m^3) and that number was found to be significantly higher than the density at all other inshore locations for October (Table 4.3).

5. Eubosmina coregoni

Eubosmina coregoni was common during the summer and fall, but it never dominated the samples (Figure 4.8). Very few individuals were observed prior to August when large numbers were first recorded. All locations displayed yearly maxima in September, ranging from 2000 to 6000 individuals/m^3. Eubosmina coregoni was again relatively rare in the fall throughout the sampling area, but the October minimum was not observed at Location 20.

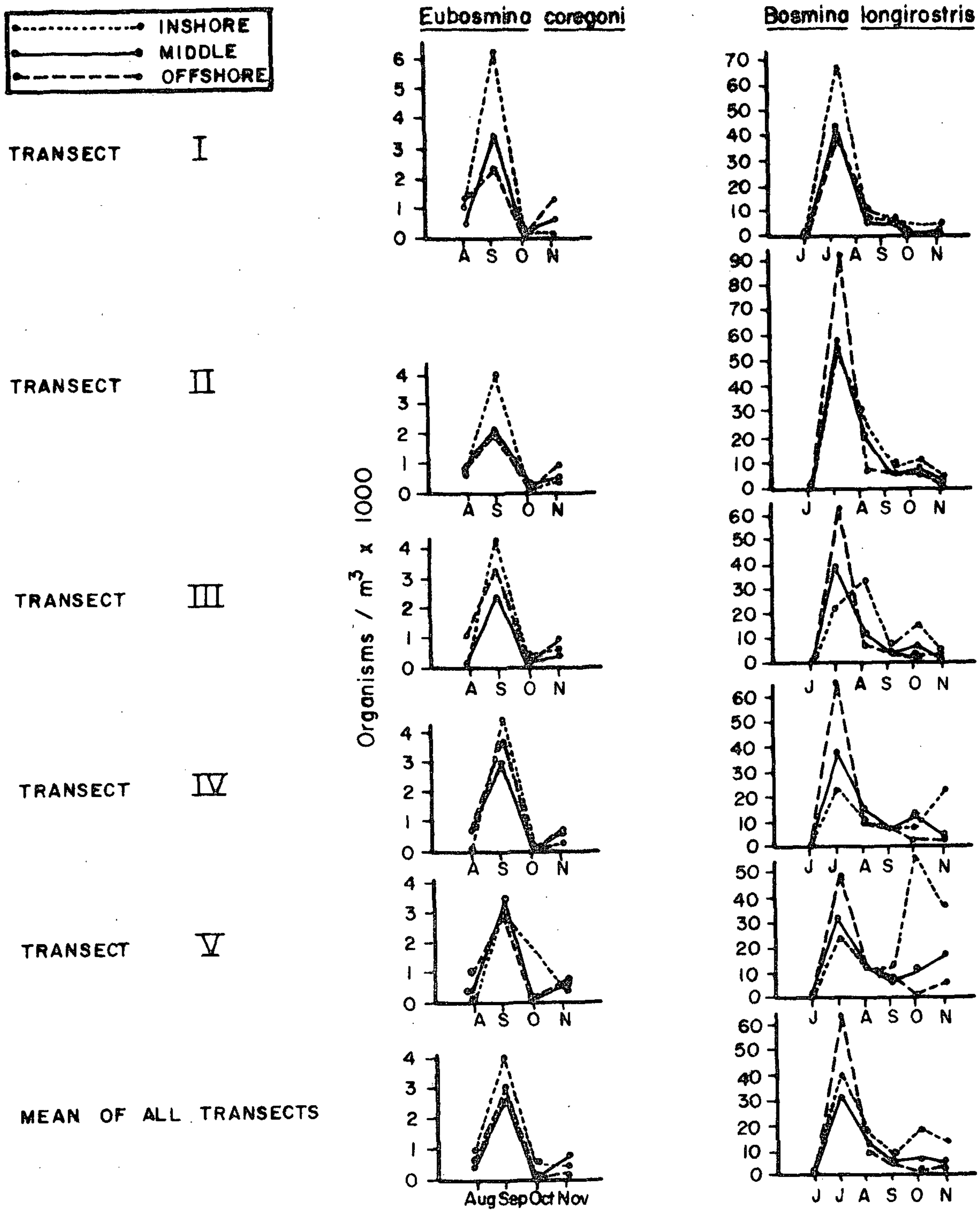

Figure 4. 8. Location densities and mean densities of Eubosmina coregoni and Bosmina longirostris collected along five transects in Lake Michigan near the Kewaunee Nuclear Power Plant, June-November 1973.

6. Daphnia spp.

Daphnia retrocurva was the most numerous of the three Daphnia spp. which were abundant in the vicinity of the KNPP (Figure 4.9). The seasonal data for this species rendered a mixed pattern of peaks and plateaus through August and September. The highest counts of D. retrocurva occurred at the offshore locations and ranged from 4000 to 8400 individuals/m^3. The general low values observed in October for all plankton was not observed for this species inshore in Transects I and II and offshore in Transect I.

Daphnia longiremis, a cold water stenotherm (Brooks 1957), was present throughout the sampling period, but was collected in largest numbers in August (Figure 4.9). The yearly maximum occurred offshore in Transect V (3500 individuals/m^3). The largest inshore and middle populations occurred on Transect II and IV, respectively.

The population of D. galeata mendota (Figure 4.9) was present throughout the eight months of collection and was greatest in September.

D. Comparisons of 1972 and 1973 Zooplankton

Comparisons between zooplankton data from 1972 and 1973 are limited by the major differences in experimental design discussed in the Introduction to this chapter. In 1972, only Transect III was sampled on the 10-, 20-, and 30-ft contour and only on a bimonthly basis. Therefore, comparisons between years will be restricted to this transect and to the nearest calendar dates. Only the crustacea will be considered since the rotifers were not enumerated in 1972 samples. Differences were noted in population densities

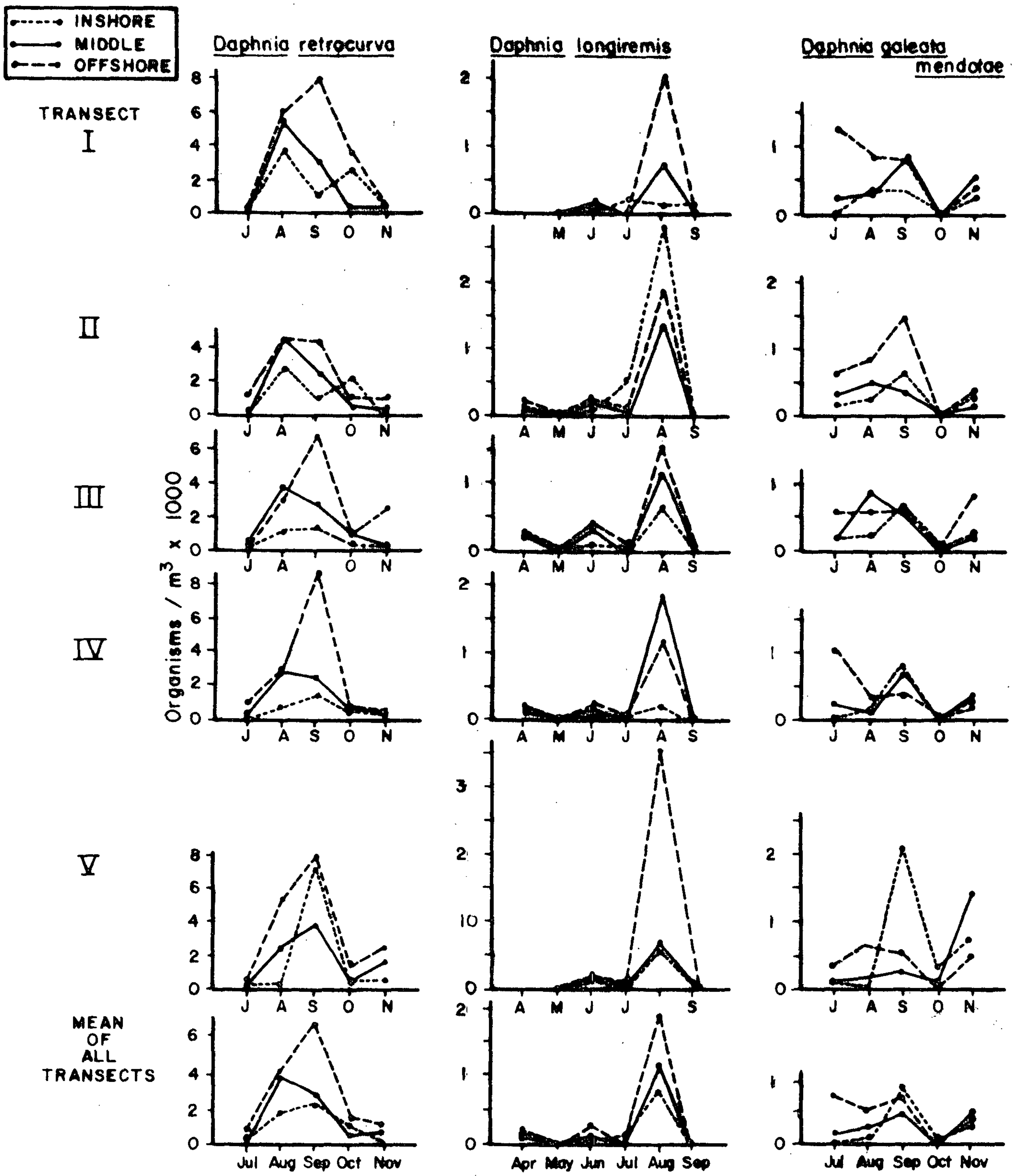

Figure 4.9. Location densities and mean densities of Daphnia retrocurva, Daphnia longiremis, and Daphnia galeata mendota collected along five transects in Lake Michigan near the Kewaunee Nuclear Power Plant, April-November 1973.

and in the seasonal occurrence of population maxima among some species and groups.

Total zooplankton abundances ranged from the May mean densities of 6100 organisms/m^3 and 4400/m^3 in 1972 and 1973, respectively, to 68000 individuals/m^3 in September 1972 and 55000/m^3 in July of 1973. In general, fluctuations in the proportions of the major groups were more subdued in 1972 than in 1973. In the earlier year the proportion of copepods to the total crustacea ranged from 32% (23000/m^3) in September to 97% (5900/m^3) in May, as contrasted to a range from 7% (4100/m^3) in June to 97% (4300/m^3) in May of 1973.

Adult copepods in May of 1972 and 1973 exhibited a sizable difference in total numbers and percent composition. In 1972 a density of 1600 adult copepods/m^3 was observed, which was approximately 25% of the total Crustacea. In 1973 a density of 240 adult copepods/m^3 was found, which represented only 4% of the total Crustacea. A difference in species composition was also observed between the May adult copepod populations of the two years. In 1972, 80% of the adults were Diaptomus spp. with most of the remainder being Cyclops bicuspidatus thomasi. In 1973, the density of adult Tropocyclops prasinus mexicanus was 13 times greater than in 1972 and constituted almost half of the copepod adults. The remainder were Diaptomus spp. and Cyclops bicuspidatus thomasi.

The increased importance of Tropocyclops prasinus mexicanus populations in May 1973 as compared to May 1972 indicated a trend that held throughout the 1973 study. During 5 months of 1973, T. prasinus mexicanus comprised from 26 to 70% of the adult Copepoda, while in 1972 it was considerably less important, never comprising more than 12% of the adult copepods. Densities of T. prasinus mexicanus showed the same trend between years ranging from 89 to 1600 organisms/m^3 in 1973 and from 7 to 460/m^3 in 1972.

Large differences were also observed between years for Bosmina longirostris. In July 1973, B. longirostris reached a density of 50000 organisms/m^3 and composed 90% of all Crustacea, while in 1972 it never reached an abundance of more than 26000/m^3 or more than 50% of the total Crustacea.

The densities of B. longirostris during November were similar (approximately 3000 organisms/m^3) in the two years, but in 1972 this density represented nearly 33% of the total Crustacea, whereas in 1973 it was less than 10%.

The November Daphnia populations, which were only 5% of the total Crustacea in 1973, composed 19% of the total in November of 1972, although the density for this month in both years was approximately 1900/m^3. The most noticeable species difference for Daphnia between the two years concerned D. retrocurva. This species had a peak density of 13000/m^3 in September of 1972 which accounted for 20% of that month's collection, but remained less than 11% of the Crustacea throughout 1973 with a maximum density of 3000 organisms/m^3 in August 1973.

IV. Summary and Conclusions

1. A total of 37 species of planktonic Crustacea were collected. Fifteen of these species were not reported in 1972. Three species that were reported in 1972 were not observed in 1973.

2. Total zooplankton populations were highest in the months of July, August, and September, and in November.

3. The most abundant taxa observed were immature Copepoda, *Bosmina longirostris*, total Rotifera, *Daphnia retrocurva*, *Cyclops bicuspidatus thomasi*, and *Tropocyclops prasinus mexicanus*.

4. Calanoid copepodites were more concentrated at offshore locations than inshore during the non-winter months.

5. Significant differences among locations did not yield discernable patterns of spatial distributions in the Kewaunee area.

6. There was a general depression in zooplankton populations during the October sampling date.

7. Fluctuations between the percentages of Copepoda and Cladocera in the total microcrustacea were more subdued in 1972 than in 1973.

8. In May of 1972 the adult copepods, particularly *Diaptomus* spp., were much more numerous than in May of 1973.

9. *Tropocyclops prasinus mexicanus* in 1973 was much more numerous and occupied a larger percentage of the copepod adults than it did in 1972.

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Chapter 5

PHYTOPLANKTON ENTRAINMENT

Karl E. Bremer and Darrell G. Redmond

PREOPERATIONAL THERMAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR KEWAUNEE NUCLEAR POWER PLANT

THIRD ANNUAL REPORT
January-December 1973

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Chapter 5

PHYTOPLANKTON ENTRAINMENT

Karl E. Bremer and Darrell G. Redmond

I. Introduction

Physiology studies of phytoplankton were initiated during 1973 at the Kewaunee Nuclear Power Plant (KNPP) to determine the effect of entrainment on organisms drawn into the Plant's once-through cooling water system. Because KNPP had not begun operations, these preoperational studies were conducted in the absence of any temperature increase through the condensers, but the normal rate of flow through the system was being produced by the operation of the circulating water pumps during periods of sampling.

The specific objectives of the first year of phytoplankton entrainment studies at the KNPP were:

1. to determine the mechanical effects of condenser passage on the phytoplankton community in the vicinity of the Plant;

2. to document the species composition and abundance of phytoplankton passing through the Plant; and

3. to determine the effects of condenser passage on the phytoplankton when chlorine was being added to the system.

The results reported in this chapter will become a part of the preoperational baseline data to which future operational data will be compared to assess the impact of KNPP on the aquatic environment.

II. Field and Analytical Procedures

Phytoplankton entrainment samples were collected monthly, March through December, from two locations in the area of the KNPP intake and discharge (Figure 2, Introduction). The intake samples were obtained from the circulating water in the forebay just prior to the traveling screens (Location E1). The discharge samples were obtained from the circulating water being discharged to Lake Michigan at the shoreline discharge structure (Location E2). One supplemental sampling was made 19 June 1973 during testing of the chlorination system at the Plant. A detailed discussion of the chlorination testing procedures is presented in Chapter 2, Water Chemistry and Bacteriology.

Phytoplankton samples were taken from a 24-liter composite water sample collected near the surface from each location, using a 6-liter Kemmerer sampler. Each composite sample was placed in a translucent carboy and maintained at intake water temperature. Three subsamples for determining chlorophyll a concentration and four subsamples for determining the rate of carbon fixation were taken from each composite sample at 7, 24, 48 and 72 hr after collection. In addition, a 1.9 liter subsample was taken from each composite sample at 7 and 72 hr after collection. These subsamples were preserved in "M^3" fixative (Meyer 1971) and used for determining species composition and density. These analyses were performed according to the methods described in Chapter 3, Phytoplankton.

Subsamples from each composite water sample were analyzed for chlorophyll a concentration at 7, 24, 48 and 72 hr after collection. Discrete subsamples were filtered through Whatman GF/C glassfiber filters on a thin layer of $MgCO_3$, eluted for at least 24 hours with 90% acetone, and subjected to ultrasonic disruption. Subsamples were then centrifuged and the floresence determined before and after addition of 1 N HCl (Lorenzen 1966). The chlorophyll a concentration in the acetone extract was determined according to the general equation of Strickland and Parsons (1968) and expressed as milligrams chlorophyll a per cubic meter (mg chlorophyll a/m^3).

The rate of carbon fixation was estimated with the light-dark bottle ^{14}C method (Parkos et al. 1969; Strickland and Parsons 1968; and Wetzel 1964). Six 50-ml subsamples (four light bottles and two dark bottles) were taken from each composite water sample at 7, 24, 48 and 72 hr after collection. Subsamples were inoculated with 4 to 5 microcuries of aqueous ^{14}C solution, agitated, and incubated in an environmental chamber at ambient lake temperature. Following incubation, the subsamples were filtered through 0.45μ porosity HA Millipore filters. The filters were dried, exposed to fumes of concentrated HCl for 10 min (Wetzel 1965) and placed in low-potassium glass scintillation vials with the algal mat facing the inside of the vial. Seventeen milliliters of scintillator fluid (12 g/l Butyl PBD, 0.4 g/l PBBO, and 180 ml/l Scintisol-Gp in spectrophotometric grade toluene) were added to each vial and the radioactivity determined using a Beckman LS-233 (refrigerated) Liquid Scintillation Counter. The rate of carbon fixation was expressed as milligrams of carbon fixed per cubic meter per hour (mg C/m^3 per hr).

Subsamples were also taken from each composite water sample at 7 and 72 hr after sample collection to check the possibility of nutrient depletion over the

3-day period during which the phytoplankton viability studies were being performed. The following chemical parameters were measured at 7 and 72 hr: ammonia, nitrate, organic nitrogen, total phosphorus, soluble orthophosphate, and silica. In addition to these water quality analyses, measurements of water temperature, pH and total alkalinity were made at 7, 24, 48 and 72 hr after sample collection. The methods for all of these analyses are listed in Chapter 2, Water Chemistry and Bacteriology.

III. Results and Discussion

A. Species Composition

Phytoplankton collected in the forebay (Location E1) and discharge (Location E2) of the Kewaunee Nuclear Power Plant during 1973 was composed of 233 taxa and 83 genera, representing seven major algal divisions. Diatoms (Bacillariophyta) comprised the greatest portion (58 to 98%) of the total phytoplankton at all times (Table 5.1). Green algae (Chlorophyta), blue-green algae (Cyanophyta), and golden-brown algae (Chrysophyta) comprised 0.2 to 6.2%, 0 to 34.5%, and 0 to 12.2% of the total phytoplankton, respectively.

Centric and pennate diatoms were the only dominant species (composed 5% or more of the total phytoplankton) throughout the study. Centric species included Stephanodiscus minutus, Stephanodiscus sp., Melosira islandica, M. italica, Cyclotella stelligera, Stephanodiscus binderanus, and Cyclotella glomerata. Pennate species included Fragilaria crotonensis, F. pinnata, Tabellaria flocculosa, Synedra filiformis, Fragilaria capucina, F. intermedia, Asterionella formosa and Nitzschia sp. A complete list of phytoplankton species identified during the study and respective densities (units/ml) are presented in Appendix 5.

B. Range of Physiology Measurements

Carbon fixation rates (a measurement of phytoplankton photosynthetic activity) and chlorophyll a concentrations (a relative index of phytoplankton biomass) ranged from 2.05 to 15.64 mg C/m^3 per hr, and from 1.08 to 15.20 mg chlorophyll a/m^3 respectively (Table 5.2). The highest carbon fixation rates and chlorophyll a concentrations were measured during the June sampling

Table 5.1. Summary of major phytoplankton groups collected in the Kewaunee Nuclear Power Plant intake (E1) and discharge (E2) and held for 72 hours, March through December 1973.

Date, Location and Time	Total Phytoplankton Reporting units/ ml	Bacillariophyta Reporting units/ml	Bacillariophyta %	Chlorophyta Reporting units/ml	Chlorophyta %	Cyanophyta Reporting units/ml	Cyanophyta %	Chrysophyta Reporting units/ml	Chrysophyta %
27 Mar 1973									
E1 - 7 hr	3446	3237	93.9	16	0.5	33	1.0	159	4.6
E_1 - 72 hr	5306	5026	94.7	13	0.3	5	0.1	261	4.9
E_2 - 7 hr	4210	3997	97.3	10	0.2	0	-	104	2.5
E_2 - 72 hr	4557	4373	96.0	43	1.0	20	0.4	120	2.6
24 Apr 1973									
E_1 - 7 hr	1835	1669	91.0	22	1.2	4	0.2	140	7.6
E_1 - 72 hr	2067	1908	92.3	47	2.3	7	0.3	105	5.1
E_2 - 7 hr	1667	1588	95.3	13	0.8	23	1.4	43	2.6
E_2 - 72 hr	1590	1483	93.3	26	1.6	2	0.1	79	5.0
15 May 1973									
E_1 - 7 hr	4851	4697	96.8	37	0.8	8	0.2	108	2.2
E_1 - 72 hr	2495	2268	90.9	80	3.2	15	0.6	131	5.3
E_2 - 7 hr	1921	1837	95.6	16	0.8	9	0.5	58	3.0
E_2 - 72 hr	2618	2301	87.9	120	4.6	1	<0.1	195	7.4
19 Jun 1973									
E_1 - 7 hr	3869	3732	96.5	61	1.6	75	1.9	2	<0.1
E_1 - 72 hr	3295	3017	91.6	147	4.5	130	4.0	0	-
E_2 - 7 hr B.C.[a]	2808	2701	96.2	53	1.9	53	1.9	1	0.1
E_2 - 72 hr B.C.	3640	3477	95.5	90	2.5	71	2.0	2	0.1
19 Jun 1973									
E_2 - 7 hrs A.C.[b]	2391	2273	95.1	46	1.9	63	2.6	9	0.4
E_2 - 72 hrs A.C.	3996	3899	97.6	73	1.8	23	0.6	1	<0.1
17 Jul 1973									
E_1 - 7 hrs	1239	1014	81.9	63	5.1	101	8.2	58	4.7
E_1 - 72 hrs	1765	1589	90.0	76	4.3	21	1.2	79	4.5
E_2 - 7 hrs	1393	1162	82.0	15	1.1	230	16.5	170	12.2
E_2 - 72 hrs	1405	1164	82.9	87	6.2	62	4.4	89	6.3
14 Aug 1973									
E_1 - 7 hrs	1519	1441	94.8	52	3.4	24	1.6	1	0.1
E_1 - 72 hrs	1701	1573	92.5	30	1.8	93	5.5	0	-
E_2 - 7 hrs	1676	1362	81.3	3	0.2	308	18.4	2	0.1
E_2 - 72 hrs	1649	1621	98.3	16	1.0	6	0.4	5	0.3

Table 5.1. Continued.

Date, Location and Time	Total Phytoplankton	Bacillariophyta		Chlorophyta		Cyanophyta		Chrysophyta	
	Reporting Units/ ml	Reporting Units/ ml	%	Reporting Units/ ml	%	Reporting Units/ ml	%	Reporting Units/ ml	%
4 Sept 1973									
E_1 - 7 hrs.	1888	1465	77.6	18	1.0	289	15.3	7	0.4
E_1 - 72 hrs	2775	2429	87.5	43	1.5	231	8.3	6	0.2
E_2 - 7 hrs	2068	1556	75.2	30	1.5	369	17.8	8	0.4
E_2 - 72 hrs	2417	2203	91.1	29	1.2	177	7.3	1	<0.1
23 Oct 1973									
E_1 - 7 hrs	2102	1547	73.6	22	1.1	477	22.7	0	-
E_1 - 72 hrs	2733	2367	86.6	33	1.2	274	10.0	0	-
E_2 - 7 hrs	1856	1077	58.0	62	3.3	640	34.5	10	0.5
E_2 - 72 hrs	1983	1773	89.4	22	1.1	183	9.2	4	0.2
18 Nov 1973									
E_1 - 7 hrs	2775	2577	92.9	28	1.0	56	2.0	1	<0.1
E_1 - 72 hrs	3930	3816	97.1	29	0.7	42	1.1	15	0.4
E_2 - 7 hrs	3727	3529	94.7	15	0.4	132	3.6	1	<0.1
E_2 - 72 hrs	4293	4199	97.8	30	0.7	31	0.7	5	0.1
18 Dec 1973									
E_1 - 7 hrs	3215	2892	90.0	32	1.3	231	7.2	27	0.8
E_1 - 72 hrs	3548	3345	94.3	57	1.6	137	3.9	9	0.3
E_2 - 7 hrs	3408	3055	89.6	48	1.4	212	6.2	49	1.4
E_2 - 72 hrs	3214	2978	92.7	51	1.6	176	5.5	9	0.3

a B.C. = Before Chlorination.
b A.C. = After Chlorination.

Table 5.2. Comparison of mean carbon fixation rates and chlorophyll a concentrations between Location E1 (intake) and Location E2 (discharge) at Kewaunee Nuclear Power Plant, March through December 1973.

Sampling Period	Time Interval After Sample Collection (hr)	Carbon Fixation ($mg\ C/m^3$. Per hr)			Chlorophyll a Concentration (mg Chlorophyll a / m^3)		
		Location E 1 (Intake)	Location E 2 (Discharge)	Significant[a] ($P \leq 0.05$)	Location E1 (Intake)	Location E 2 (Discharge)	Significant[a] ($P \leq 0.05$)
27-30 March	7	7.98[b]	6.92	Yes	6.40[c]	6.13	No
	24	9.24	8.65	No	7.20	6.80	No
	48	8.14	7.46	Yes	7.20	7.47	No
	72	8.40	7.25	Yes	6.80	6.80	No
24-27 April	7	9.34	7.89	Yes	5.73	4.93	Yes
	24	10.03	8.38	Yes	5.60	5.33	No
	48	5.27	4.59	Yes	5.87	5.33	No
	72	4.79	4.16	Yes	6.13	4.80	Yes
15-28 May	7	9.58	10.08	No	7.60	7.33	No
	24	4.88	4.56	No	7.73	7.20	No
	48	8.66	8.53	No	8.67	6.67	Yes
	72	3.67	3.64	No	8.93	8.27	No
19-22 June	7	15.64	13.45	Yes	15.20	12.00	Yes
	24	9.10	8.95	No	13.47	12.00	Yes
	48	6.84	6.19	No	13.47	11.20	Yes
	72	6.39	5.91	No	14.00	10.13	Yes
19-22 June[d]	7	15.64	4.64	Yes	15.20	8.40	Yes
	24	9.10	2.05	Yes	13.47	7.20	Yes
	48	6.84	2.30	Yes	13.47	7.20	Yes
	72	6.39	2.55	Yes	14.00	7.20	Yes
17-20 July	7	7.88	6.54	Yes	4.13	3.87	No
	24	5.47	5.03	No	4.00	3.47	Yes
	48	3.94	3.90	No	3.73	3.33	Yes
	72	3.64	3.78	No	3.47	3.20	No
14-17 August	7	8.59	7.66	Yes	6.93	6.80	No
	24	6.37	5.44	Yes	6.53	6.67	No
	48	5.41	4.37	Yes	7.06	6.67	No
	72	5.55	4.32	Yes	6.80	6.80	No

Table 5.2. Continued.

Sampling Period	Time Interval After Sample Collection (hr)	Carbon Fixation (mg C/m^3 per hr) Location E1 (Intake)	Carbon Fixation (mg C/m^3 per hr) Location E2 (Discharge)	Significant[a] (P≤ 0.05)	Chlorophyll a Concentration (mg Chlorophyll a/m^3) Location E1 (Intake)	Chlorophyll a Concentration (mg Chlorophyll a/m^3) Location E2 (Discharge)	Significant[a] (P≤ 0.05)
4-7 September	7	8.10	6.11	Yes	6.80	6.93	No
	24	5.50	3.59	Yes	6.40	5.87	No
	48	4.62	2.71	Yes	4.80	5.87	No
	72	4.01	2.51	Yes	5.87	4.80	No
23-26 October	7	8.57	7.31	Yes	3.60	3.47	No
	24	5.35	5.68	No	3.60	4.00	No
	48	6.37	5.39	Yes	3.33	3.20	No
	72	6.06	4.96	Yes	3.60	3.20	No
18-21 November	7	9.43	8.73	Yes	1.12	1.12	No
	24	7.84	6.09	Yes	1.11	1.12	No
	48	5.58	4.44	Yes	1.17	1.12	No
	72	5.02	3.48	Yes	1.15	1.08	No
11-14 December	7	9.33	7.60	Yes	7.07	6.40	Yes
	24	10.44	9.45	Yes	7.73	6.53	Yes
	48	8.44	7.73	Yes	6.27	6.27	No
	72	6.65	6.84	No	6.27	6.13	No

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[a] Determined by Factorial Analysis of Variance and Tukey's Multiple Comparison Procedure.
[b] Mean of four replicates.
[c] Mean of three replicates.
[d] Chlorine applied to discharge samples (0.10 mg/l total chlorine detected).

period. The lowest rate of carbon fixation occurred in July for Location E1 and in September for Location E2. The lowest chlorophyll a concentrations occurred in November. The lowest recorded rates of carbon fixation were measured in samples from the discharge (Location E2) during the June sampling period after the addition of chlorine.

C. Entrainment Effects

1. Mechanical Effects

The mechanical effects (pump effects) on entrained phytoplankton were measured from March through December as ratios of intake values (Location E1) to discharge values (Location E2). Ratios less than 1.0 indicated a reduction of carbon fixation rate, of chlorophyll a concentration, or of phytoplankton abundance at the discharge; ratios greater than 1.0 indicated an increase in carbon fixation rate, in chlorophyll a concentrations, or in phytoplankton abundance at the discharge. Generally, a slight initial inhibition of phytoplankton photosynthesis measured by carbon fixation rate was detected at the discharge (Figure 5.1). This level of inhibition remained relatively constant during the 72-hr test periods. The mean inhibition of photosynthesis (March through December) was 13.5% at the discharge when compared with the intake (Table 5.3). This inhibition effect was significant ($P \leq 0.05$) in 27 of 40 comparisons of carbon fixation rate between the intake and discharge (Table 5.2).

Generally, a slight initial reduction in chlorophyll a concentrations was detected at the discharge (Figure 5.1). This level of reduction remained relatively constant during the 72-hr test periods. While no great initial

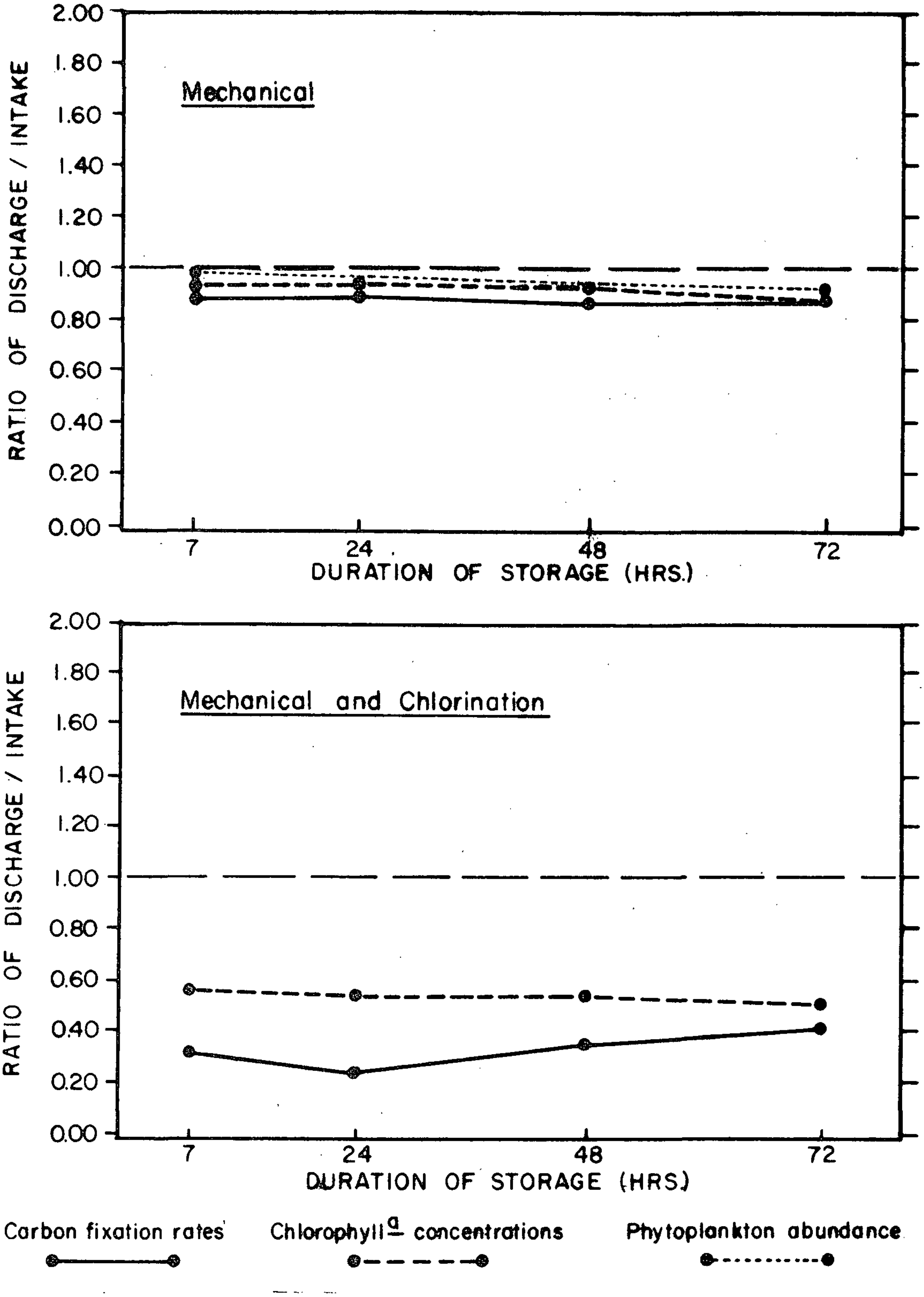

Figure 5.1. Mechanical and chlorination effects as ratios of phytoplankton productivity (carbon fixation rate), chlorophyll a concentration, and phytoplankton abundance for Location E2 (discharge)/ Location E1 (intake), Kewaunee Nuclear Power Plant, March through December 1973. (Ratios less than 1.0 indicate inhibition and values greater than 1.0 indicate stimulation).

Table 5.3. Summary of physical data and reductions in photosynthesis, chlorophyll *a* concentrations and phytoplankton abundance obtained at Kewaunee Nuclear Power Plant, March through December 1973.

Sampling Period	Number of Pumps in Operation	Water Temperature at Intake and Discharge	% Reduction in photosynthesis (Carbon Fixation Rate) at Discharge	% Reduction in Chlorophyll *a* Concentration at Discharge	% Reduction in Total Phytoplankton Abundance	Dominant Phytoplankton Species Reduced in Number 72 hr after Passage through the Plant
27-30 March	2	3.8 C (38.8 F)	10	1	14	*Fragilaria crotonensis* *Fragilaria pinnata* *Tabellaria flocculosa*
24-27 April	2	7.0 C (44.6 F)	14	12	23	*Tabellaria flocculosa* *Stephanodiscus minutis* *Stephanodiscus* spp.
15-28 May	2	9.8 C (49.6 F)	1	10	0	None
19-22 June	2	10.0 C (50.0 F)	8	19	0	None
	2[a]	10.0 C (50.0 F)	68	47	0	None
17-20 July	1	13.0 C (55.4 F)	5	9	20	*Fragilaria crotonensis* *Asterionella formosa* *Stephanodiscus* spp.
14-17 August	2	12.0 C (53.6 F)	17	1	3	*Tabellaria flocculosa* *Melosira islandica* *Melosira italica* *Stephanodiscus* spp. *Cyclotella stelligera*
4-7 September	1	8.5 C (47.3 F)	34	0	13	*Synedra filiformis*
23-26 October	1	10.2 C (50.4 F)	18	11	27	*Fragilaria crotonensis* *Melosira italica*
18-21 November	2	2.0 C (35.6 F)	20	18	0	None
11-14 December	1	0.5 C (32.9 F)	8	7	10	*Fragilaria crotonensis* *Fragilaria pinnata* *Stephanodiscus* spp.
Annual mean (without chlorine)			13.5	9	11	

[a] Total Chlorine level at discharge 0.10 mg/l.

decrease was noted for mean numbers of phytoplankton, the data showed a slight decrease over the 72-hr periods (Figure 5.1). Mean reductions at the discharge in chlorophyll a concentrations and numbers of phytoplankton were 9% and 11% respectively from March through November (Table 5.3). Reductions in chlorophyll a concentration, however, were only significant ($P \leq 0.05$) in 11 of 40 comparisons (Table 5.2).

Nutrient concentrations for ammonia, nitrate, orthophosphate, and silica were generally similar between the intake and discharge during all sampling periods (Appendix 5). In addition, changes in nutrient concentrations during the 72 hr storage period indicated that nutrient levels were not limiting for algal productivity in any samples collected.

Percent reductions in phytoplankton photosynthesis, chlorophyll a concentration, and total phytoplankton abundance for the year during normal sampling ranged from 1 to 34%, 0 to 19%, and 0 to 27% respectively (Table 5.3). In general, the degree of reduction was not dependent on the number of pumps in operation nor on ambient temperatures. Similar studies by Flemer et al. (1971) indicated that mechanical effects of power plant operation reduced phytoplankton photosynthesis and chlorophyll a concentrations by 21 and 22% respectively.

Specific phytoplankton species were reduced in number at 72 hours after sample collection in certain of the discharge samples (Table 5.3). The species most often reduced in abundance after entrainment were Fragilaria crotonensis and to a lesser extent Tabellaria flocculosa and Synedra filiformis.

These species are long slender fragile pennate diatoms. During March, April, July, September, October and December, one or more of these species were significantly reduced in the discharge when compared with the intake. This reduction was accompanied by reductions in photosynthesis and chlorophyll a concentrations.

2. Mechanical and Chlorination Effects

The combined mechanical and chlorination effect on entrained phytoplankton was measured on 19 June by comparing intake and discharge samples during a period when the KNPP system for chlorinating the condensers was being tested. Chlorine was added to circulating water to determine effective concentrations in the condensers and associated levels in the water being discharged to the lake (cf. Chapter 2. Water Chemistry and Bacteriology). The total chlorine level measured in the discharge at the time of sampling was 0.10 mg/l.

Phytoplankton photosynthesis and chlorophyll a concentrations were significantly ($P \leq 0.05$) reduced by 68% and 47% respectively in the discharge when compared with the intake (Table 5.2 and 5.3) during chlorination. Recovery of viability, as determined by these measurements, was not observed during the 72 hour study period (Figure 5.1). Similar studies by Restaino et al. (1973), Brook and Baker (1972), and Morgan and Stross (1969) demonstrated a similar inhibition effect on phytoplankton photosynthesis and reduction of chlorophyll a concentration due to chlorination.

Average nutrient uptake by phytoplankton of ammonia, nitrate, and orthophosphate as measured by the decrease in concentrations in water samples was generally similar between the intake and discharge samples during the chlorination study. Uptake of silica by phytoplankton, however, was lower for discharge samples than for those from the intake during the 72 hour storage period.

IV. Summary and Conclusions

1. Reductions in carbon fixation rate (a measurement of phytoplankton photosynthetic activity) ranged from 1 to 34% at the discharge when compared with the intake during normal sampling conditions, with an annual mean reduction of 13.5%. Twenty-seven of the 40 comparisons made showed that the reduction was significant ($P \leq 0.05$).

2. Reductions in chlorophyll a concentrations (a relative index of phytoplankton biomass) ranged from 0 to 19% at the discharge when compared with the intake during normal sampling conditions, with an annual mean reduction of 9%. Eleven of the 40 comparisons made showed that the reduction was significant.

3. Reductions in phytoplankton abundance (density) ranged from 0 to 27% at the discharge when compared with the intake. The mean annual reduction was 11%.

4. Diatoms (Bacillariophyta) composed the greatest portion of the total phytoplankton passing through the Plant during the period from March through December. The pennate diatoms, Fragilaria crotonensis, Tabellaria flocculosa, and Synedra filiformis were frequently reduced in number following entrainment.

5. Significant reductions ($P \leq 0.05$) in carbon fixation rate and chlorophyll a concentration were observed at the discharge as compared with the intake during special chlorination testing when a total chlorine level of 0.10 mg/l was measured in the discharge.

6. Recovery of phytoplankton viability, as determined by carbon fixation rates and chlorophyll a concentrations, was not detected during the 72-hr period after sample collection during the chlorination study.

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Chapter 6

ZOOPLANKTON ENTRAINMENT

Daniel L. Wetzel and Anthony L. Restaino

PREOPERATIONAL THERMAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR KEWAUNEE NUCLEAR POWER PLANT

THIRD ANNUAL REPORT
January-December 1973

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Chapter 6

ZOOPLANKTON ENTRAINMENT

Daniel L. Wetzel and Anthony L. Restaino

I. Introduction

Zooplankton entrainment studies were initiated in March 1973 and were conducted monthly through December at the Kewaunee Nuclear Power Plant (KNPP). The objectives of the first year of zooplankton entrainment studies at the KNPP were:

1. to determine the mechanical effects of condenser passage, without heat, on the zooplankton from Lake Michigan in the Plant vicinity;
2. to document the abundance and species composition of zooplankton passing through the Plant; and
3. to study the effects of chlorination on zooplankton physiology.

The studies reported in this chapter were designed to determine the effect of entrainment of zooplankton drawn into the Plant's once-through cooling water system. Results form a part of the preoperational baseline data.

II. Field and Analytical Procedures

Samples were collected monthly from the KNPP circulating cooling water system, March through December 1973 at Location E1 and Location E2 (Figure 2, Introduction). Location E1 was in the forebay of the Plant's intake. Location E2 was in the discharge canal outlet at the shoreline prior to mixing with Lake Michigan waters. An additional sample was collected at the discharge on 19 June during chlorination testing to determine the effects of chlorination on zooplankton physiology. A detailed discussion of the chlorination testing procedures and results is presented in Chapter 2, Water Chemistry and Bacteriology.

Duplicate samples for zooplankton analyses were collected near the water's surface at both locations with a filter-pump system similar to that described by Icanberry (1972). A #10 mesh (153μ aperture) filter was used in the filter-pump sampling system to collect a representative zooplankton sample. Each sample was concentrated to a 200 ml volume and maintained at intake water temperature. Subsamples were taken from each concentrated sample with an automatic pipette, placed in a compartmented Petri dish, and examined under a stereozoom microscope. Motile and immotile individuals were separated within 20 min and at 4 hr after sample collection.

Zooplankton were recorded initially as "motile" and "immotile" rather than living and dead because condenser passage can produce temporary shock which may be mistaken for death. "Immotility" is defined herein as the absence of appendicular and visceral movement upon probing and is used principally to describe the initial (0 hr) condition of organisms following collection. The term "mortality" denotes those organisms which failed to become motile after 4 hr and were recorded as "live" and "dead." The percent immotility or mortality of zooplankters for each sample was calculated using the following formula:

$$\frac{\text{Number of immotile or dead zooplankton per sample}}{\text{Total zooplankton per sample}} \times 100 = \begin{array}{l}\text{\% immotility or}\\ \text{mortality}\end{array}$$

The percent differential immotility or mortality of zooplankters due to condenser passage was determined by the following formula:

(% discharge immotility or mortality) minus (% intake immotility or mortality) = (% differential immotility or mortility due to entrainment)

At the conclusion of each survival analysis, zooplankton were preserved in 3% formalin, and species composition and abundance (density) were determined from the discharge samples. Analyses followed methods described in Chapter 4, Zooplankton. Identifications were made using taxomonic keys by Brooks (1957 and 1966), Wilson and Yeatman (1959) and Gannon (1970).

The relationship between mechanical effects of condenser passage and size of organisms was assessed by ranking the five to seven most abundant species from the survival study according to size, using the measurement criteria of Gannon (personal communication, letter dated 13 October 1971 from Dr. J. E. Gannon, University of Michigan) and Wells (1970).

Significant ($P \leq 0.05$) differences between motile and immotile and between live and dead abundances of major zooplankton taxa were determined each month by chi-square analyses. A one-way analysis of variance was used to determine significant differences between abundances of zooplankton taxa from month to month.

III. Results and Discussion

Results of sample analyses for species identification, abundance and survival are presented in Appendix 6.

A. Abundance

Zooplankton abundance was relatively low prior to August 1973. Zooplankton abundance was high from August through December, with the August density (40451 organisms/m^3) being significantly higher ($P \leq 0.05$) than that in all other months (Table 6.1 and 6.2). From the August high, zooplankton density gradually decreased to 8842/m^3 in November. December abundance increased to 10676/m^3. From March through July, zooplankton abundance ranged between a low of 494/m^3 in March and a high of 6681/m^3 in June.

Population densities for both copepods and cladocerans tended to peak during the same seasonal periods in 1973. One peak occurred for cladocerans in August (29485/m^3); for copepods, two peaks occurred, one in June (6238/m^3) and one in September (15706/m^3) (Table 6.1). Copepods were more abundant than cladocerans except in July and August. In August, Bosmina longirostris (Cladocera) population were significantly higher ($P \leq 0.05$) than that in all other months (Table 6.2).

In spring and summer, calanoid and cyclopoid copepodites were most abundant reaching peaks of 600 and 2661 organisms/m^3 respectively in June, and 1422/m^3 and 9388/m^3 respectively in early September (Table 6.1). Nauplii were most abundant in June and September (848/m^3 and 996/m^3 respectively).

Table 6.1. Zooplankton densities (No./m^3) at Kewaunee Nuclear Power Plant, March through December, 1973.

Organisms	Sampling Dates										
	March	April	May	June	June[a]	July	August	September	October	November	December
Total Zooplankton	494	1902	1087	6681	4358	1648	40451	23675	14588	8842	10676
Total Cladocera	1	18	60	443	150	919	29485	7969	6704	3403	3120
Alona affinis	0	0	1	0	0	0	0	0	0	0	34
Alona monacantha	0	0	0	0	0	0	0	0	0	0	0
Alona rectangula	0	0	0	11	0	0	0	0	0	0	0
Bosmina longirostris	0	11	54	168	88	842	28607	6601	6184	2351	617
Chydorus sphaericus	0	0	0	81	22	6	0	541	80	0	17
Daphnia spp (Immature)	0	2	0	15	0	2	49	143	0	0	150
Daphnia galeata mendotae	0	0	0	0	0	0	98	0	0	551	584
Daphnia longiremis	1	4	4	168	40	40	341	484	0	0	0
Daphnia parvula	0	0	1	0	0	0	0	0	0	0	0
Daphnia retrocurva	0	0	0	0	0	21	390	0	300	501	67
Eubosmina coregoni	0	1	0	0	0	8	0	171	100	0	1651
Holopedium gibberum	0	0	0	0	0	0	0	0	40	0	0
Ilyocryptus sordidus	0	0	0	0	0	0	0	29	0	0	0
Total Copepoda	493	1883	1027	6238	4208	729	10966	15706	7884	5439	7556
nauplii	23	151	532	709	848	39	390	996	40	34	34
calanoid copepodites	2	25	137	600	749	438	1170	1422	280	467	0
cyclopoid copepodites	32	91	49	2661	1338	55	5458	9388	6744	2318	917
Cyclops bicuspidatus thomasi	62	312	127	1192	559	47	3753	2504	120	301	4186
Cyclops vernalis	0	0	0	40	0	0	0	0	120	0	17
Diaptomus ashlandi	69	303	28	51	30	11	49	29	0	100	750
Diaptomus minutus	53	21	10	0	8	0	0	0	0	250	117
Diaptomus oregon nsis	4	59	1	0	0	2	0	0	0	1551	1185
Diaptomus sicilis	10	19	0	0	0	0	0	57	0	100	100
Diaptomus spp. (female)	226	875	75	783	665	130	146	1224	-[b]	-	-
Epischura lacustris	0	0	0	0	0	0	0	0	60	17	0
Eurytemora affinis	0	0	3	172	11	0	0	0	20	0	0
Lernea affinis	0	0	0	0	0	0	0	29	0	0	0
Limnocalanus macrurus	4	0	0	0	0	0	0	0	0	0	0
Mesocyclops edax	0	0	0	0	0	0	0	57	20	0	0
Paracyclops fimbriatus poppei	0	0	0	0	0	0	0	0	0	0	0
Tropocyclops prasinus	3	15	62	4	0	7	0	0	480	234	150
Harpacticoida	5	12	3	26	0	0	0	0	0	67	100

[a] Samples taken during chlorination.

[b] As of October, all Diaptomus females were keyed to species.

Table 6.2. Summary of one-way ANOVA with Tukey's multiple comparison of zooplankton abundance at Kewaunee Nuclear Power Plant, March through December 1973.

Organisms	One-way ANOVA F Ratio	One-way ANOVA P^a	Tukey's Multiple Comparison
Total zooplankton	262.777	0.001	Aug > Mar, Apr, May, Jun, Jul, Sep, Oct, Nov, Dec
			Sep > Mar, May, Jul, Apr, Jun, Nov, Dec, Oct
			Oct > Mar, May, Jul, Apr, Jun, Nov, Dec
			Dec > Mar, May, Jul, Apr, Jun
			Nov > Mar, May, Jul, Apr, Jun
			Jun > Mar, May, Jul, Apr
			Apr > Mar
Copepoda cyclopoid copepodites	4.322	0.016	Sep > Mar, Jul, Apr, May
Cyclops bicuspidatus thomasi	51.052	0.001	Aug > Jul, Mar, May, Nov, Apr, Oct, Jun
			Dec > Jul, Mar, May, Nov, Apr, Oct, Jun
			Sep > Jul, Mar, May, Nov, Apr, Oct, Jun
			Jun > Jul, Mar, May

Table 6.2. Continued

Organisms	One-way ANOVA F Ratio	One-way ANOVA P^a	Tukey's Multiple Comparison
Diaptomus spp. (female)	19.160	0.001	Sep > Oct, Nov, Dec, Aug, May, Jul
			Apr > Oct, Nov, Dec, Aug, May, Jul
			Jun > Oct, Nov, Dec
Diaptomus ashlandi	10.759	0.001	Dec > Mar, Oct, May, Jun, Jul, Sep, Aug, Nov
			Apr > Oct
Bosmina longirostris	23.10677	0.001	Aug > Mar, Apr, May, Jun, Dec, Jul, Nov, Oct, Sep
			Sep > Mar, Apr, May, Jun, Dec, Jul, Nov
			Oct > Mar, Apr, May, Jun, Dec, Jul
			Nov > Mar, Apr, May, Jun, Dec
			Jul > Mar, Apr

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[a] Significance level $P \leq 0.05$

Cyclops bicuspidatus thomasi population density was significantly greater ($P \leq 0.001$) in August, September and December than that in all remaining months, averaging $3281/m^3$ (Table 6.1 and 6.2). Diaptomus spp. (female) was present in all samples. The females were keyed to species from October through December. Diaptomus species attained their highest population densities in November and December, averaging 2076 organisms/m^3.

The most prevalent cladoceran was Bosmina longirostris (Table 6.1). Bosmina longirostris abundance increased gradually from April ($11/m^3$) to July, then increased significantly to the August peak ($28607/m^3$), decreased significantly ($P \leq 0.05$) in September ($6601/m^3$), and continued to decline through December (Table 6.2). Daphnia longiremis was present from April ($4/m^3$) through September ($484/m^3$) with peak abundance occurring in September. Daphnia retrocurva and Daphnia galeata mendotae were present in summer, late fall and early winter (Table 6.1).

B. Survival

Immotilities for total zooplankton based on chi-square analyses of live-dead ratios at 0 hr were highly significant ($P \leq 0.01$) for every month except September and October (Table 6.3). These immotility values, indicating adverse mechanical effects on total zooplankton viability immediately after condenser passage, were highest (10.7%) in July (Table 6.4). Immotilities for immature copepods varied monthly but were usually higher for calanoid and cyclopoid copepodites than for nauplii.

Table 6.3. Chi-square analysis of live-dead ratios of major entrained (discharge) to non-entrained (intake) zooplankton at Kewaunee Nuclear Power Plant, March through December 1973.

Date/Major Taxa	Chi-square values 0 hr	 4 hr
March		
nauplii	3.1048	i.d.
cyclopoid copepodites	1.1503	4.0444*
Diaptomus spp. (female)	11.3803***	0.0865
Diaptomus ashlandi	0.4139	0.0005
Diaptomus minutus	1.4024	3.1906
Cyclops bicuspidatus thomasi	3.9858*	2.7331
Total Zooplankton	15.5753***	7.1133**
April		
nauplii	8.7032***	8.4010***
cyclopoid copepodites	i.d.[a]	4.6720*
Cyclops bicuspidatus thomasi	12.1061***	12.9331***
Diaptomus ashlandi	10.2609***	7.4337**
Diaptomus minutus	1.8498	2.1818
Total Zooplankton	79.3401***	31.8565***
May		
nauplii	0.1528	0.2637
Cyclopoid copepodites	4.0179*	0.0017
Cyclops bicuspidatus thomasi	1.8153	2.7726
Tropocyclops prasinus	i.d.	i.d.
Diaptomus spp. (female)	0.9564	1.2393
Bosmina longirostris	i.d.	i.d.
Total Zooplankton	6.8049**	6.8565**
June		
nauplii	0.3443	0.6207
cyclopoid copepodites	5.8850*	0.1342
calanoid copepodites	4.0515*	0.0131
Cyclops bicuspidatus thomasi	0.0776	0.0001
Diaptomus spp. (female)	0.1962	0.5315
Total zooplankton	7.5976**	1.3359
July		
calanoid copepodites	35.3573***	9.7530***
Diaptomus spp. (female)	0.1030	0.8874
Bosmina longirostris	10.4119***	0.5845
Total Zooplankton	40.7327***	2.1999

Table 6.3. Continued

Date/Major Taxa	Chi-square Values O hr	 4 hr
August		
cyclopoid copepodites	0.2730	0.5147
Cyclops bicuspidatus thomasi	5.1462*	1.5808
Bosmina longirostris	5.6272*	1.4986
Total Zooplankton	11.8482***	2.6240
September		
cyclopoid copepodites	0.5980	1.5137
Cyclops bicuspidatus thomasi	0.5659	0.3561
Diaptomus spp.(female)	1.3994	6.0698*
Bosmina longirostris	0.0044	0.5250
Total Zooplankton	0.1711	0.0385
October		
cyclopoid copepodites	0.0636	4.0713*
Bosmina longirostris	0.5184	2.2514
Total Zooplankton	3.4766	9.2561***
November		
cyclopoid copepodites	9.1386***	12.7269***
Diaptomus oregonensis	0.3086	1.2854
Bosmina longirostris	0.6586	2.9680
Total Zooplankton	10.3055***	19.0880***
December		
cyclopoid copepodites	4.0424*	5.9644*
Cyclops bicuspidatus thomasi	4.3279*	0.5645
Diaptomus ashlandi	0.0450	0.2214
Diaptomus oregonensis	0.0359	4.3710*
Bosmina longirostris	0.7172	2.2222
Eubosmina coregoni	0.6991	1.9460
Total Zooplankton	11.3622***	8.0238***

* Significant at the 0.05 level.
** Significant at the 0.01 level.
*** Significant at the 0.005 level.
a i.d. means insufficient data.

Table 6.4. Summary of percent differential immotilities or mortalities from zooplankton survival data of intake and discharge samples analyzed at 0 and 4 hr after collection at the Kewaunee Nuclear Power Plant, March through December, 1973.

Organisms[a]	March % Differential Immotility[b]	March % Differential Mortality[b]	April % Differential Immotility	April % Differential Mortality	May % Differential Immotility	May % Differential Mortality	June % Differential Immotility	June % Differential Mortality	June (chlorinated) % Differential Immotility	June (chlorinated) % Differential Mortality	July % Differential Immotility	July % Differential Mortality
Total Zooplankton	9.4	6.4	6.8	7.2	3.6	3.5	5.2	2.2	5.5	9.6	10.7	3.9
Total Cladocera	0.0	0.0	11.8	10.0	6.2	5.6	11.9	5.7	15.6	20.0	7.8	0.0
Bosmina longirostris	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	0.0
Eubosmina coregoni	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Copepoda	9.4	6.5	6.8	7.3	3.3	3.5	4.9	2.3	5.2	9.2	16.1	14.7
nauplii	0.0	0.0	0.0	0.0	0.6	0.9	3.2	0.0	0.0	0.0	22.9	20.7
calanoid copepodites	0.0	0.0	0.0	0.0	4.3	6.7	0.0	0.0	0.0	0.0	0.0	0.0
cyclopoid copepodites	0.0	0.0	0.0	0.0	0.0	0.0	6.8	0.9	0.0	0.0	0.0	0.0
Cyclops bicuspidatus thomasi	16.6	9.7	5.5	9.0	7.0	9.8	1.1	0.0	0.0	0.0	0.0	0.0
Diaptomus ashlandi	3.2	0.1	5.3	10.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diaptomus minutus	0.0	9.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diaptomus oregonensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diaptomus spp. (female)	11.9	1.2	8.4	2.5	0.0	0.0	0.0	7.9	0.0	0.0	0.0	0.0

Table 6.4. Continued.

Organisms[a]	August % Differential Immotility	August % Differential Mortality	September % Differential Immotility	September % Differential Mortality	October % Differential Immotility	October % Differential Mortality	November % Differential Immotility	November % Differential Mortality	December % Differential Immotility	December % Differential Mortality
Total Zooplankton	6.5	3.9	0.7	0.0	3.2	4.7	6.6	11.5	8.6	7.2
Total Cladocera	6.8	4.4	0.0	0.0	5.1	6.5	5.0	9.3	9.1	16.2
Bosmina longirostris	5.4	3.1	0.1	1.8	2.6	4.4	3.1	6.7	0.0	0.0
Eubosmina coregoni	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	8.9
Total Copepoda	5.0	1.3	2.6	0.1	1.1	2.9	7.9	12.3	7.7	4.5
nauplii	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
calanoid copepodites	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
cyclopoid copepodites	0.0	0.0	0.1	0.0	0.5	3.0	10.4	14.5	0.0	0.0
Cyclops bicuspidatus thomasi	0.0	0.0	4.7	3.7	0.0	0.0	0.0	0.0	0.0	0.0
Diaptomus ashlandi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diaptomus minutus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diaptomus oregonensis	0.0	0.0	0.0	0.0	0.0	0.0	4.2	11.6	2.9	22.2
Diaptomus spp. (female)	0.0	0.0	0.0	0.0	-c	-c	-c	-c	-c	-c

---

[a] Only those organisms which comprised >10% of the zooplankton community in a given month are included.

[b] % differential immotility/mortality = % immotilities/mortalities at discharge minus % immotilities/mortalities at intake.

[c] After September, all *Diaptomus* spp. (female) were keyed to species.

When small organisms such as immature copepods and Bosmina longirostris composed a high percentage of the entire population, the percent immotility from condenser passage was lowest, reflecting few, if any, effects from mechanical damage. In March, when small organisms ($\leq$ 0.40mm) composed 11.5% of the total zooplankton (Table 6.1), 9.4% of total zooplankton were immotile (Table 6.4). In April, when small organisms composed 14.7% of the total zooplankton, 6.8% of total zooplankton were immotile. From May through October, except July, small zooplankton ($\leq$ 0.40 mm) averaged 80.3% of the population and had a 3.8% mean immotility. November and December populations averaged 56.2% small organisms, and 7.6% were immotile. July immotilities were exceptionally high at 10.7% (Table 6.4) with 83.7% of the zooplankton being small organisms.

In general, percent immotility of entrained organisms varied directly with zooplankton size. Entrained organisms which exceeded 1.11 mm in length (e.g. Limnocalanus macrurus, Daphnia retrocurva and D. galeata mendotae) had a differential immotility averaging 9.8% (Table 6.5). Zooplankton under 0.41 mm (e.g. cyclopoid and calanoid copepodites, nauplii, and Bosmina longirostris) averaged 3.7% immotility. Binomial regression analysis showed that immotility of entrained zooplankton was a linear function of size (Figure 6.1), indicating that mechanical effects of condenser passage were more detrimental to large organisms than to small ones.

There was a 45% average recovery of immotile organisms 4 hr after entrainment in seven of the ten months of testing, resulting in a 3.9% average

Table 6.5. Initial length measurements and percent immotility of entrained and non-entrained zooplankton at Kewaunee Nuclear Power Plant, March through December 1973.

Total Length of Organisms (mm)		Location E1 (intake)				Location E2 (discharge)				
Range	Mean	Motile	Immotile	Total	Percent Immotile	Motile	Immotile	Total	Percent Immotile	Differential Immotility
0.00-0.40	0.32	1400	51	1451	3.5	1575	122	1697	7.2	3.7
0.41-0.80	0.49	1484	81	1565	5.2	1105	157	1262	12.4	7.2
0.81-1.10	0.95	2162	89	2251	4.0	2287	269	2556	10.5	6.5
>1.11	1.38	389	23	412	5.6	416	76	492	15.4	9.8

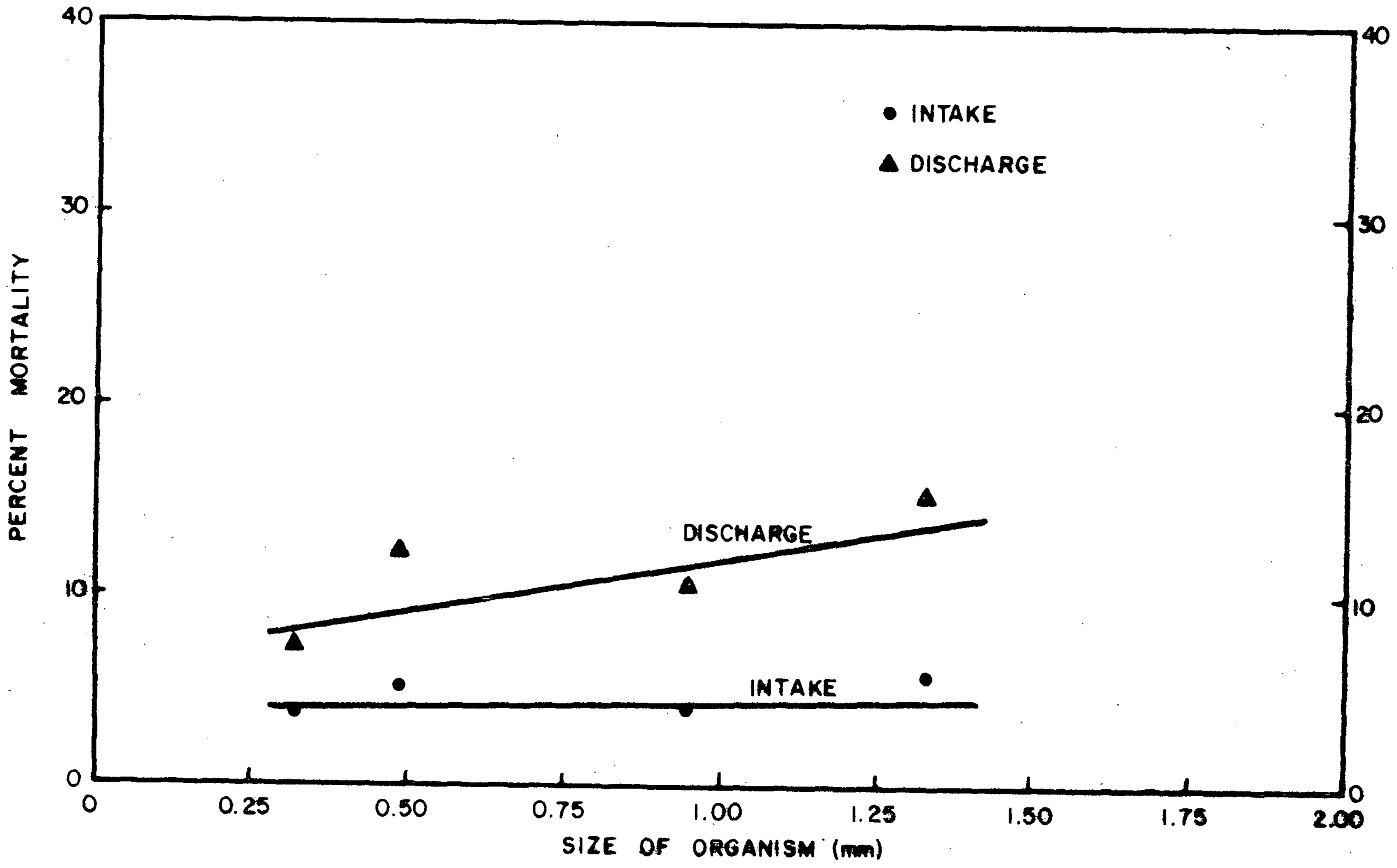

Figure 6.1. Binomial regression analysis (size vs. mortality) for zooplankton subjected to condenser passage at Kewaunee Nuclear Power Plant, March through December 1973.

mortality. In April, October and November, there was a 2.3% average delayed mortality at 4 hr. During these months, immotility averaged 5.5% and mortality 7.8% (Table 6.4).

The total effect of entrainment at the Kewaunee Nuclear Power Plant was a reduction in viability for some zooplankton (Figure 6.2). The average zooplankton viability before entrainment in spring (March through June) and fall (October through December) was 94.7%. Viability before entrainment in summer (July through September) averaged 91.8%. Entrainment reduced viability to 88.6% in the spring and fall and to 89.3% in the summer (Figure 6.2). The net effect for the year was a 5.1% reduction in zooplankton viability due to mechanical entrainment effects.

On 19 June, zooplankton entrainment samples were collected while the KNPP chlorination system was being tested. With a 0.10 ppm concentration of residual chlorine in the discharge water, the resulting differential immotility and mortality was 5.5 and 9.6%, respectively for total zooplankton (Table 6.4). Immotilities and mortalities were increased significantly ($P \leq 0.05$) for cyclopoid copepodites, Cyclops bicuspidatus thomasi and total zooplankton (Table 6.6). This was a slight increase over the non-chlorinated differential immotility of 5.2% for that month, but a marked increase over the non-chlorinated differential mortality of 2.2%.

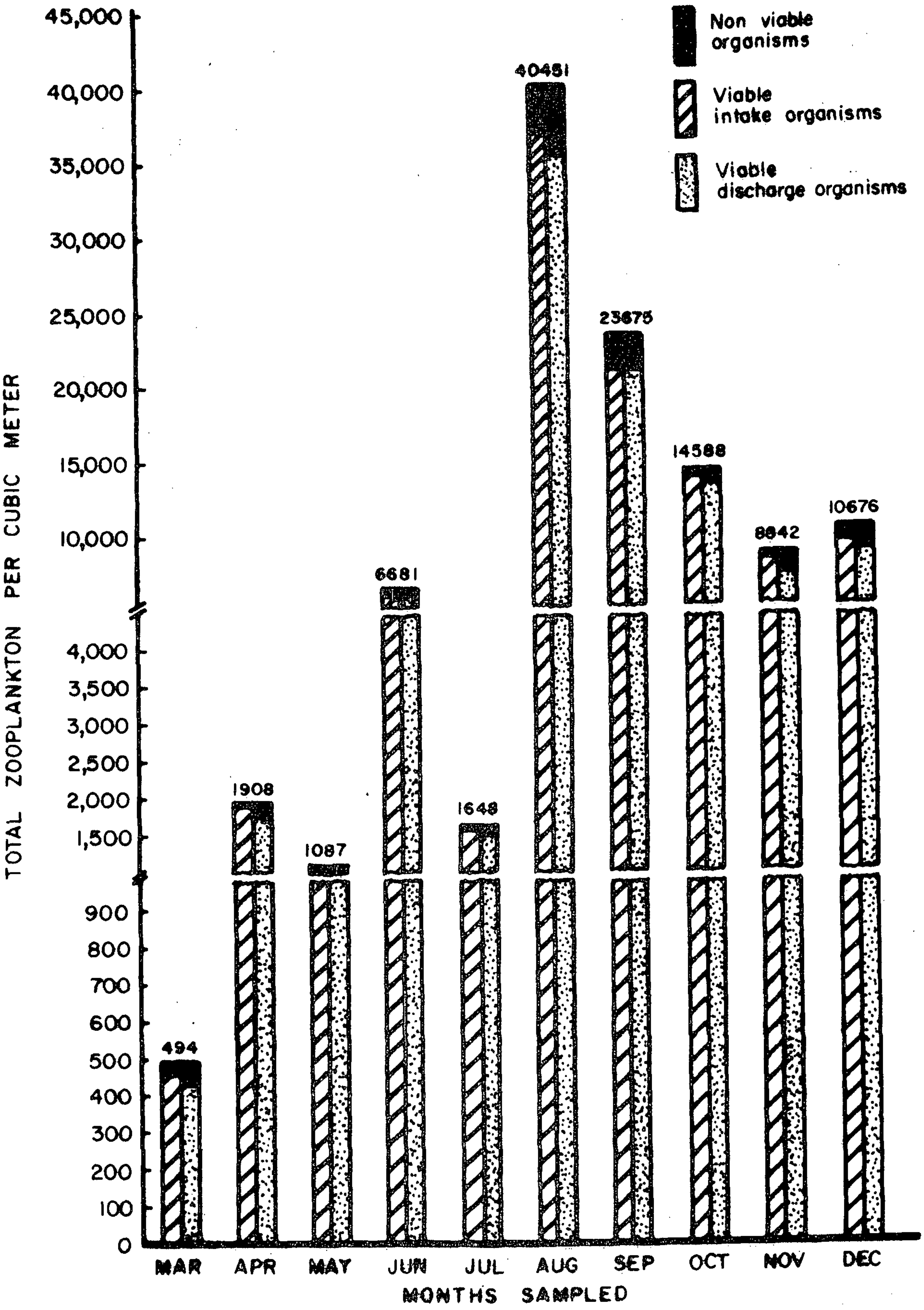

Figure 6.2. Viable and non-viable zooplankton before and after entrainment at Kewaunee Nuclear Power Plant, March through December 1973.

Table 6.6. Chi-square analysis of live-dead ratios of major entrained (discharge) to non-entrained (intake) zooplankton, chlorinated samples taken in June 1973 at the Kewaunee Nuclear Power Plant.

Organisms	Chi-square Values	
	0 hr	4 hr
nauplii	0.0052	1.2934
cyclopoid copepodites	7.4575**	6.3519*
calanoid copepodites	0.0864	0.0214
<u>Cyclops</u> <u>bicuspidatus</u> <u>thomasi</u>	5.8947*	5.0785*
<u>Diaptomus</u> spp. (female)	0.0559	0.7790
Total Zooplankton	8.1099***	17.6023***

* Significant at the 0.05 level.
** Significant at the 0.01 level.
*** Significant at the 0.005 level.

IV. Summary and Conclusions

1. Total zooplankton abundance was greatest from August through December.

2. Population densities for both Copepoda and Cladocera tended to peak during the same seasonal periods.

3. Immotilities for total zooplankton were highly significant ($P \leq 0.01$) for every month except September and October.

4. When small organisms such as immature copepods and Bosmina longirostris comprised a high percentage of the entire population, the percent immotility from condenser passage was generally low and reflected few, if any, effects from mechanical damage.

5. Binomial regression analyses showed that immotility of entrained zooplankton was a linear function of size.

6. There was a 45% average recovery of immotile zooplankton 4 hr after entrainment in seven of the ten months of testing, resulting in a 3.9% average mortality.

7. Zooplankton viability showed an average reduction of 5.1% for the year due to mechanical entrainment effects.

8. Chlorination of condenser cooling water in June resulted in increased immotility and mortality of zooplankton present.

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Chapter 7

PERIPHYTON

Howard J. Delinck

PREOPERATIONAL THERMAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR KEWAUNEE NUCLEAR POWER PLANT

THIRD ANNUAL REPORT
January-December 1973

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Chapter 7

PERIPHYTON

Howard J. Delinck

I. Introduction

In this chapter is presented the preoperational baseline information for the third consecutive year related to the periphyton (attached algae) community in the vicinity of the Kewaunee Nuclear Power Plant (KNPP). The specific objectives of the study were:

1. to characterize available substrate types in the vicinity of the Plant;
2. to determine species composition and diversity, relative abundance, and biovolume of periphyton growing on natural substrates in the Plant vicinity; and
3. to evaluate the temporal and spatial distributions of the periphyton near KNPP.

II. Field and Analytical Procedures

Periphyton was sampled bimonthly starting in May 1973 on 21 May, 23 July, 24 September, and 7 November, from natural substrates at three shoreline locations (Figure 1, Introduction). The absence of perceptable periphytic growth precluded the scheduled sampling in April. Three samples were collected at each sampling location from adjacent rock substrates within the "splash zone" (surface to 15 cm below surface). Each sample consisted of the periphytic growth from two 10 cm^2 areas which were delimited with a rectangular steel template. The algal material was scraped from the delimited area, placed in a sample vial, and preserved in a 4% formalin solution.

The samples from each location were analyzed for species composition, relative abundance and biovolume. Each sample was adjusted to a uniform volume, mixed thoroughly, and divided into two equal portions; one portion for diatom and the other for non-diatom (green and blue-green) analyses. The diatoms were cleaned with concentrated nitric acid, and later identified and counted from Hyrax mounts (Boyer 1916; Patrick and Reimer 1966) at 1250X magnification. Non-diatoms were identified and counted from wet mounts at 500X magnification. A 10.8 mm^2 area under each coverslip (50 x 24 mm) was examined for both diatoms and non-diatoms. Taxonomic keys used for identifications included Hustedt (1930), Patrick and Reimer (1966), Prescott (1962), Smith (1950), and Tiffany and Britton (1952). Relative abundance of each algal taxon was reported as the number of individuals per square centimeter (No/cm^2).

Cell biovolume was calculated quarterly from 10 randomly selected individuals of each taxon. Biovolume was calculated using the geometric equation that best suited the shape of each taxon (Vollenweider 1969). The average volume was recorded as the biovolume of that particular taxon. Biovolume was expressed as microliters per square decimeter ($\mu l/dm^2$).

The Shannon-Weaver species diversity (HI) and evenness (E) indices (Shannon and Weaver 1949) were used to estimate the differences in community structure between the three sampling locations.

III. Results and Discussion

A. Substrates

The Lake Michigan shoreline in the vicinity of the Kewaunee Nuclear Power Plant is characterized by a narrow beach composed of fine sand, which grades to gravel and rubble with increased distance from shore (Poff and Threinen 1966). Shoreline substrates capable of supporting periphytic growth in the study area were conspicuously lacking. Concrete slabs and wooden pilings constituted the primary substrates at the southernmost location (Location 18) (Figure 1, Introduction). Rip-rap provided the only substrate at Location 9 near the KNPP. Substrates at the northernmost sampling location (Location 1) were extremely sparse and consisted mainly of small to moderately sized rocks and clay outcrops.

B. Community Structure and Species Composition

1. Total Periphyton

The periphytic algal assemblage sampled from natural substrates near the Kewaunee Nuclear Power Plant in 1973 was composed of 114 taxa representing three algal divisions: Bacillariophyta (diatoms), Chlorophyta (green algae) and Cyanophyta (blue-green algae). A listing of all periphyton taxa collected, and their abundance and biovolume are presented in Appendix 7.

Relative abundance of total periphyton varied between locations and showed a general increase from May to November at all locations, except Location 1 in July and Location 18 in September (Table 7.1). Periphytic algal numbers ranged from a low of 998,458 individuals/cm^2 in May to a high of

Table 7.1. Mean relative abundance and percent composition of major algal divisions collected from natural shoreline substrates in Lake Michigan near the Kewaunee Nuclear Power Plant, May through November 1973.

Sampling Date and Location	Bacillariophyta		Chlorophyta		Cyanophyta		Total Periphyton
	No./cm^2	%	No./cm^2	%	No./cm^2	%	No./cm^2
21 May 1973							
1	2,398,140	70.8	0	0.0	990,740	29.2	3,388,880
9	365,743	36.6	632,715	63.4	0	0.0	998,458
18	2,495,362	94.7	0	0.0	138,889	5.3	2,634,251
23 July 1973							
1	7,778	0.3	2,459,502	99.7	0	0.0	2,467,279
9	272,224	7.7	3,239,872	91.5	30,247	0.8	3,542,342
18	1,139,869	22.9	3,634,809	72.9	209,136	4.2	4,983,813
24 Sept. 1973							
1	694,444	7.3	8,805,540	92.6	7,407	<0.1	9,507,394
9	396,300	4.4	8,499,984	95.6	0	0.0	8,896,284
18	372,223	14.4	2,125,921	82.4	83,333	3.2	2,581,477
7 Nov. 1973							
1	4,737,644	30.9	10,601,842	69.1	0	0.0	15,339,481
9	748,456	2.5	28,672,802	96.9	169,753	0.6	29,590,994
18	216,048	2.1	10,038,572	97.9	0	0.0	10,254,621

29,590,944 individuals/cm^2 in November, both at Location 9.

Mean total periphyton biovolume differed considerably between locations and between sampling periods. Biovolume ranged from a low of 24.268 µl/dm^2 at Location 1 in May to a high of 13,288.902 µl/dm^2 at Location 9 in November (Table 7.2). Changes in biovolume occurred primarily in conjunction with fluctuations in the abundance of green filamentous algae.

2. Bacillariophyta

Bacillariophyta (diatoms) were present in samples throughout the study and included 91 taxa representing 13 genera. Diatoms accounted for over 70% of the mean number of individuals (Table 7.1) and over 90% of the mean total biovolume (Table 7.2) in May at Locations 1 and 18 where no green algae were present. However, diatoms accounted for only 37% of the population and 12% of the biovolume at Location 9 in May where green algae dominated. Diatoms never accounted for more than 31% of the periphytic community after May.

The diatom taxa which were dominant (composed over 5% of the periphyton community) during the study included Gomphonema olivaceum, Fragilaria intermedia, Fragilaria construens and Fragilaria vaucheriae in the spring; F. vaucheriae in the summer and fall; and Cymbella prostrata in the fall (Table 7.3). With the exception of F. intermedia and F. construens, all of the above diatoms were considered abundant in the 1972 study (Industrial BIO-TEST Laboratories, Inc. 1973). Gomphonema olivaceum and F. vaucheriae colonized artificial substrates (plexiglass slides) and were reported as being abundant in studies conducted near the Point Beach Nuclear Power Plant (University of

Table 7.2. Mean biovolume and percent composition of major algal divisions collected from natural substrates in Lake Michigan near the Kewaunee Nuclear Power Plant, May through November 1973.

Date and Location	Bacillariophyta		Chlorophyta		Cyanophyta		Total Periphyton
	µl/dm²	%	µl/dm²	%	µl/dm²	%	µl/dm²
21 May 1973							
1	22.072	90.9	0.000	0.0	2.246	9.1	24.268
9	4.289	12.4	29.865	87.6	0.000	0.0	34.104
18	37.385	99.1	0.000	0.0	0.343	0.0	37.728
23 July 1973							
1	0.044	<0.1	145.102	99.9	0.000	0.0	145.147
9	2.358	0.3	726.744	99.7	0.056	<0.1	729.108
18	14.860	1.1	1,333.314	98.9	0.352	<0.1	1,348.477
24 Sept. 1973							
1	2.902	0.3	1,099.742	99.7	0.005	<0.1	1,102.551
9	7.400	3.3	218.109	96.7	0.000	0.0	225.460
18	1.956	1.7	110.848	98.3	0.041	<0.1	112.746
7 Nov. 1973							
1	149.216	5.8	2,398.762	94.2	0.000	0.0	2,547.879
9	26.151	0.2	13,262.701	99.8	0.050	<0.1	13,288.902
18	1.865	<0.1	6,109.820	99.9	0.000	0.0	6,111.590

Table 7.3. Periphytic algal taxa composing 5% or more of the mean number of individuals or mean total biovolume from shoreline collections at three locations in Lake Michigan near the Kewaunee Nuclear Power Plant, May through November 1973.

Date, Location and Taxon	Mean Number of Individuals No. /cm^2	%	Mean Total Biovolume µl/dm^2	%
21 May 1973:				
Location 1				
Bacillariophyta				
Gomphonema olivaceum	763,888	22.5	11.756	48.5
Fragilaria intermedia	472,222	13.9	3.093	12.8
F. vaucheriae	435,185	12.8	1.518	6.3
F. construens	384,259	11.3	1.567	6.4
Cyanophyta				
Phormidium uncinatum	810,185	23.9	0.972	4.0
Calothrix parietana	180,555	5.3	1.224	5.1
Location 9				
Bacillariophyta				
Gomphonema olivaceum	179,012	17.9	2.754	8.1
Fragilaria construens	55,556	5.6	0.226	0.7
Chlorophyta				
Ulothrix zonata	294,753	29.5	25.142	73.8
U. aequalis	219,135	21.9	3.887	11.4
U. variabilis	118,827	11.9	0.785	2.3
Location 18				
Bacillariophyta				
Gomphonema olivaceum	2,338,886	90.7	36.549	97.0
Cyanophyta				
Oscillatoria amoena	138,887	5.3	0.343	0.9
23 July 1973:				
Location 1				
Chlorophyta				
Ulothrix zonata	1,915,059	77.6	129.266	89.1
Stigeoclonium subsecundum	466,666	18.9	13.999	9.6
Location 9				
Chlorophyta				
Ulothrix zonata	3,200,983	90.4	726.238	99.6

Table 7.3. Continued.

Date, Location and Taxon	Mean Number of Individuals		Mean Total Biovolume	
	No. /cm^2	%	µl/dm^2	%
Location 18				
Chlorophyta				
Cladophora glomerata	2,720,490	54.6	1305.835	96.8
Ulothrix zonata	914,319	18.3	27.429	2.0
24 September 1973:				
Location 1				
Chlorophyta				
Ulothrix zonata	6,775,914	71.3	1075.337	97.5
Cladophora glomerata	2,029,626	21.3	24.355	2.2
Location 9				
Chlorophyta				
Cladophora glomerata	8,499,984	95.6	218.109	96.7
Location 18				
Bacillariophyta				
Fragilaria vaucheriae	146,296	5.7	0.438	0.4
Chlorophyta				
Cladophora glomerata	1,459,256	56.5	39.516	35.1
Ulothrix zonata	333,333	12.9	65.026	57.7
Stigeoclonium subsecundum	249,999	9.7	2.029	1.8
7 November 1973:				
Location 1				
Bacillariophyta				
Cymbella prostrata	2,199,072	14.3	127.942	5.0
Fragilaria vaucheriae	1,342,591	8.8	3.933	0.2
Chlorophyta				
Cladophora glomerata	9,212,949	60.1	2300.657	90.3
Ulothrix zonata	1,388,888	9.1	98.055	3.8
Location 9				
Chlorophyta				
Cladophora glomerata	28,325,587	95.7	13.241.403	99.6
Location 18				
Chlorophyta				
Cladophora glomerata	9,344,128	91.1	6013.129	98.4
Ulothrix zonata	694,444	6.8	96.645	1.6

Wisconsin - Milwaukee 1970a, 1971a, 1972a) and the Kewaunee Nuclear Power Plant (University of Wisconsin - Milwaukee 1970b, 1971b, 1972b, 1973).

3. Chlorophyta

Chlorophyta (green algae) composed the major portion of the periphyton community from July to November. This division accounted for 63 to 99% of the mean number of individuals (Table 7.1) and 87 to 99% of the mean total biovolume (Table 7.2) at all locations for all months, except for Locations 1 and 18 in May where diatoms were dominant. In general, the growth of green algae increased from spring to fall and reached its maximum at all locations in November. Ulothrix aequalis, Ulothrix variabilis, Ulothrix zonata, Stigeoclonium subsecundum, and Cladophora glomerata were the only species of green algae collected (Appendix 7) and all were dominant at some time during the study (Table 7.3).

Ulothrix zonata and C. glomerata represented the majority of the periphytic growth during the study. A pattern of seasonal succession was apparent for these two species and was most pronounced at Location 9 (Table 7.4). Ulothrix zonata was present on rip-rap substrates in May when water temperatures averaged 10C. It became abundant on substrates by July, but was replaced by C. glomerata in September when water temperatures averaged 16.2C. Cladophora glomerata remained abundant at Location 9 in November even though water temperatures decreased to 6.2C.

The seasonal succession pattern was not as evident at Locations 1 and 18 where U. zonata and C. glomerata were absent in May but occurred

Table 7.4. Comparison of seasonal growth of Ulothrix zonata and Cladophora glomerata collected from natural shoreline substrates at three locations in Lake Michigan near the Kewaunee Nuclear Power Plant, May through November 1973.

	Sampling Locations					
	1		9		18	
Sampling Date	U. zonata	C. glomerata	U. zonata	C. glomerata	U. zonata	C. glomerata
21 May 1973						
Number/cm^2	0	0	294,753	0	0	0
% Occurrence	-	-	29.5	-	-	-
Microliters/dm^2	0	0	25	0	0	0
% Composition	-	-	73.8	-	-	-
23 July 1973						
Number/cm^2	1,915,059	0	3,200,983	0	914,319	2,720,490
% Occurrence	77.6	-	90.4	-	18.3	54.6
Microliters/dm^2	129	0	726	0	27	1,306
% Composition	89.1	-	99.6	-	2.0	96.8
24 September 1973						
Number/cm^2	6,775,914	2,029,626	0	8,499,984	333,333	1,459,256
% Occurrence	71.3	21.3	-	95.6	12.9	56.5
Microliters/dm^2	1,075	24	0	218	65	40
% Composition	97.5	2.2	-	96.7	57.7	35.1
7 November 1973						
Number/cm^2	1,388,888	9,212,949	0	28,325,587	694,444	9,344,128
% Occurrence	9.1	60.1	-	95.7	6.8	91.1
Microliters/dm^2	98	2,300	0	13,241	97	6,013
% Composition	3.8	90.3	-	99.6	1.6	98.4

together thereafter. Their individual percent composition varied between locations and sampling dates, except in November when C. glomerata accounted for over 60% of the total mean number of individuals and over 90% of the biovolume at Locations 1 and 18 (Table 7.4). Ulothrix zonata represented less than 9% of the total mean number of individuals and less than 4% of the biovolume at both locations in November.

Ulothrix zonata and C. glomerata are common to Lake Michigan. These two algal taxa have been found on shoreline substrates near Two Creeks, Wisconsin (University of Wisconsin - Milwaukee 1971a, 1972a), near the Kewaunee Nuclear Power Plant (University of Wisconsin - Milwaukee 1971b, 1972b, 1973; Industrial BIO-TEST Laboratories, Inc. 1972a, 1973) and in the Zion - Waukegan area of Illinois (Industrial BIO-TEST Laboratories, Inc. 1972b). Herbst (1969) had also found these taxa along the Milwaukee breakwall and related their dominance patterns to water temperature differences. Ulothrix zonata usually occurs in water temperatures below 15C (Blum 1956; McNaught 1964) while C. glomerata experiences optimal growth at water temperatures from 16 to 28C (McNaught 1964; McMillan and Verduin 1953; Storr and Sweeney 1971). Bellis and McLarty (1967) reported that U. zonata appeared commonly in winter and spring and that C. glomerata was the dominant alga during the warmer months from May to September. They concluded that fluctuations in the production of C. glomerata were more dependent upon seasonal variations in meteorological conditions than on differences in the dissolved nutrient substances, and that vegetative development appeared to be stimulated by increasing solar radiation. McMillan and Verduin (1953) also concluded that the temperature for optimal growth of C. glomerata was about 17C with high light intensity, and that U. zonata experienced optimal growth at about 4C under low light intensity. Both species are rheophilic, colonizing substrates in areas where water movement is not restricted (Herbst 1969).

4. Cyanophyta

Cyanophyta (blue-green algae) represented a small portion of the periphyton community in the Kewaunee area. This division composed over 5% of the total mean number of individuals only in May (Table 7.1) at Locations 1 and 18, and over 5% of the biovolume at Location 1 in the same month (Table 7.2). Eight taxa belonging to five genera of blue-green algae were identified (Appendix 7). Dominant blue-green algae included Phormidium tenue, Calothrix parietana and Oscillatoria amoena (Table 7.3). No distributional pattern was evident for Cyanophyta, although it was present at one or more locations during each sampling period throughout the study.

5. Comparison of 1971, 1972 and 1973 Periphyton

A comparison of the species composition of periphyton during 1971, 1972 and 1973 near the KNPP indicated that there were no changes beyond normal species variation. Changes in the abundant species, especially the diatom species Cocconeis pediculus, Fragilaria pinnata and Rhoicosphenia curvata, can be attributed to the changes in the methods used to determine relative abundance of taxa between 1973 and the two previous studies in 1971 and 1972. In the first two studies, relative abundance was determined by the presence or absence of a particular taxon in a specific number of microscopic fields; in the 1973 study, however, each cell was identified and counted in a defined area of the slide.

In all three years of preoperational monitoring, the total periphyton was composed of species representing the three algal divisions, Bacillariophyta, Chlorophyta and Cyanophyta. Only in 1972 were species of Rhodophyta (red algae) identified in periphyton samples, and then this division composed a very small portion of the community.

C. pH and Nutrients

The presence of algal species and their growth are influenced by the pH and nutrient content of the water in addition to light intensity and water temperature. Cladophora glomerata, for example, requires a pH range of 7.5 to 8.5 (Herbst 1969) and high nutrient levels (Whitton 1970). Herbst (1969) stated that concentrations of 0.3 mg/l for inorganic nitrogen and 0.03 mg/l for phosphorus are generally accepted as critical concentrations which, if not exceeded, will limit excessive algal growth if all other conditions remain favorable. The concentrations of nitrate, monitored in conjunction with the water chemistry studies reported in Chapter 2, never exceeded this hypothetical critical concentration for nitrogen, and total phosphorus exceeded this hypothetical critical concentration only in April (0.034 to 0.063 mg/l) and September (0.035 to 0.040 mg/l) at Locations 2, 11 and 20 near the periphyton sampling locations. No excessive shoreline growths of attached algae should be expected in the sampling area if the nutrient levels present remain unchanged.

D. Temporal and Spatial Distribution

The species composition of the periphyton community varied between locations and sampling periods. Species diversity and evenness values were highest in May at Locations 1 and 9 (Table 7.5) where no one taxa constituted over 30% of the total number of individuals (Table 7.3). Gomphonema olivaceum composed over 90% of the total number of individuals at Location 18 in May (Table 7.3), resulting in low species diversity and evenness values (Table 7.5). A similar decrease in diversity and evenness values was evident at Location 9 between May and November. This decrease was caused by the disproportionately large populations of Ulothrix zonata in July, which composed 90% of the periphyton community, and Cladophora glomerata in September and November, which accounted for more than 95% of the community (Table 7.3). The difference in community structure between locations could have been caused by the difference in the type of substrate sampled. The substrate at Location 18 was concrete slabs, whereas, at Location 9 the substrate was rip-rap, and at Location 1, the substrate was small to moderately sized rocks and clay outcrops.

Table 7.5. Shannon-Weaver species diversity index and evenness values for periphytic species collected from natural shoreline substrates at three locations in Lake Michigan near the Kewaunee Nuclear Power Plant, May through November 1973.

Date and Location	Total Periphyton (No./cm^2)	Number of Species	Diversity (HI)	Evenness (E)
21 May 1973				
1	3,388,880	24	3.01	0.66
9	998,458	21	2.86	0.65
18	2,634,252	19	0.68	0.16
23 July 1973				
1	2,467,279	7	0.93	0.33
9	3,542,342	31	0.80	0.16
18	4,983,813	46	2.32	0.42
24 Sept. 1973				
1	9,507,394	24	1.29	0.28
9	8,896,284	31	0.40	0.08
18	2,581,477	20	2.29	0.53
7 Nov. 1973				
1	15,339,481	36	2.09	0.41
9	29,590,994	16	0.38	0.10
18	10,254,621	12	0.56	0.16

IV. Summary and Conclusions

1. One hundred-fourteen periphytic algal taxa were collected from natural substrates, representing the Bacillariophyta (diatoms), Chlorophyta (green algae) and Cyanophyta (blue-green algae) divisions.

2. Total periphytic abundance and biovolume varied between locations and showed a general increase from May to November. Differences between locations could have been due in part to the different types of substrates sampled at each location.

3. Bacillariophyta (diatoms) were present throughout the study and were represented by 91 taxa belonging to 13 genera. Diatoms represented the majority of the periphytic community in May but decreased in abundance in subsequent months. Gomphonema olivaceum, Fragilaria intermedia, Fragilaria construens, Fragilaria vaucheriae and Cymbella prostrata were the dominant diatom species collected during the study.

4. Chlorophyta (green algae) comprised the major portion of the periphytic community after May and was represented by five taxa belonging to three genera. Green algae increased in abundance and biovolume throughout the study period. Ulothrix zonata and Cladophora glomerata represented the majority of the periphytic growth of the two species in the study area. Ulothrix zonata was dominant in May and July, while C. glomerata was dominant in September and November.

5. Cyanophyta (blue-green algae) represented a small portion of the periphytic community and was composed of eight taxa belonging to five genera.

Dominant blue-green algal species included Phormidium tenue, Calothrix parientana and Oscillatoria amoena.

6. There were no changes in periphytic species composition beyond normal species variation between the 1973 study and the 1971 and 1972 studies. Changes in abundant diatom taxa were attributed to the different analytical methods used to determine relative abundance.

7. Concentrations of the major nutrients, nitrate and total phosphorus, were below hypothetical critical levels that could result in excessive growths of attached algae.

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Chapter 8

BENTHOS

Joseph H. Rains and Thomas V. Clevenger

PREOPERATIONAL THERMAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR KEWAUNEE NUCLEAR POWER PLANT

THIRD ANNUAL REPORT
January-December 1973

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Chapter 8

BENTHOS

Joseph H. Rains and Thomas V. Clevenger

I. Introduction

The preoperational characterization of the benthic community in the vicinity of the Kewaunee Nuclear Power Plant (KNPP) was continued in 1973 and results are reported in this chapter. The specific objectives of this study were:

1. to determine the species composition and abundance of benthic organisms;
2. to document the normal distribution of organisms both in space (locations) and in time (seasons);
3. to characterize bottom substrates associated with sampling locations and species found;
4. to establish a standardized sampling technique; and
5. to compare 1973 data with that previously collected as a part of the preoperational studies.

A number of changes related to sampling methodology have occurred during the preoperational study period. During the 1971 studies (Industrial BIO-TEST Laboratories, Inc. 1972c), bottom samples containing sediments and benthos were collected with a Ponar grab sampler and sieved with a 30 mesh (595μ aperture) screen on which the organisms were retained. Numbers and types of organisms collected were very low, due to the fact that the Ponar did not adequately sample the rocky substrate commonly found in the vicinity of KNPP. Also there was concern that many of the smaller organisms collected were not retained by the 30 mesh screen. In 1972 (Industrial BIO-TEST Laboratories, Inc. 1973), an experimental collection system involving a benthic pump ai a 100 mesh (150 aperature) screen was developed and employed in an attempt to obtain a more complete sample from a given area of bottom and to sample smaller organisms, thus providing a more accurate estimate of the benthic community. Using these new sampling methods, the number of organisms collected increased 30 times over the number collected in 1971 and resulted in a six-fold increase in the number of taxa identified.

In the present study (1973), samples were collected in a manner similar to 1972 using a benthic pump, but with a few exceptions. Samples in 1973 were serially sieved using a 30 and a 100 mesh screen rather than just a 100 mesh screen. Data obtained from the 30 mesh samples permitted comparisons to be made with those from other research work in which 30 mesh screens are regularly employed. Discussions of 1973 results pertain only to 30 mesh data, but in the comparisons with 1972 results, 30 mesh data were combined with 100 mesh data to provide the continuity in data evaluation. Also in the present study the number of replicates and the size of the area sampled was changed. In the 1972 study in the vicinity of the KNPP, two replicate samples were taken at each location and the area sampled varied from 1/4 sq m to 1 sq m. In the present study (1973), three replicate samples were taken at each location and the area sampled was reduced to 1/8 sq m. It was rationalized that more replicate samples would give a more reliable estimate of mean benthic abundance and the smaller area sampled could be more thoroughly sampled by the diver.

II. Field and Analytical Procedures

Benthos samples were collected from nine locations on 13 April, 22 May, 24 July, 28 September and 16 November (Figure 1, Introduction). Sampling locations were positioned on the basis of depth and distance from the point of Plant discharge. Two locations were along the 10-ft depth contour (Locations 6 and 11), four were along the 20-ft depth contour (Locations 3, 7, 12 and 16), and three were along the 30-ft depth contour (Locations 8, 13 and 17). Three replicate samples were collected from each location by a SCUBA diver using a one-eighth square meter metal frame and a variable speed, gasoline driven, centrifugal pump with a 3 in diameter intake hose, and 380 gpm capacity. The diver arbitrarily placed the frame on the lake bottom in a location which had no rocks larger than one-third the area of the frame. The diver disturbed the sediments and scoured the rocks within the enclosed area, while manipulating the pump's suction hose to pick up the disturbed materials. Suspended material, the top layer of silt and sand, and associated benthos were conveyed to the surface, and passed into a #10 mesh (153μ aperture) plankton net. Each sample was placed in a plastic bag and preserved in 10% formalin. Each sample was serially sieved using a U. S. Standard No. 30 mesh (595μ aperture) and a U. S. Standard No. 100 mesh (150μ aperture) sieve in the laboratory. When 100 mesh samples contained a large amount of sand, a carbon tetrachloride floatation metho was used to separate the organisms from the sand (Whitehouse and Lewis 1966).

All organisms retained on the 30 and 100 mesh sieves were identified to the lowest positive taxa, except the Chironomidae and Oligochaeta retained by the

100 mesh sieve, which were not identified further. All organisms were reported in numbers per square meter (No./m^2). Taxonomic keys used for identification include the following: Beatty (1970), Bousfield (1958) Brinkhurst (1964 and 1965), Brinkhurst and Cook (1966), Brinkhurst and Jamieson (1971), Burks (1953), Hamilton and Saether (1970), Hamilton et al. (1969), Harman and Berg (1971), Heard (1972), Hiltunen (1973), Pennak (1953), Roback (1957), Ross (1944), Saether (1973), Sperber (1950), and Walter and Burch (1957).

Significant ($P \leq 0.05$) differences in abundances of dominant taxa among locations along the 20- and 30-ft depth contours were determined for each sampling date using a one-way analysis of variance (ANOVA). Significant differences between the 10-ft locations were determined by Student's "t" test. Significant differences in abundances of dominant taxa between 1972 and 1973 for July, September and November were determined by the Uniformly Most Powerful Unbiased Test for Poisson Means (Lehmann 1959).

Shannon (1948), Brillouin (1956) and Margalef (1951) formulae were used to determine species diversity values for 30 mesh data obtained from each location on each sampling date. Unidentifiable immature Tubificidae were excluded from the statistical analyses when determining species diversity values.

III. Results and Discussion

A. Substrate Characterization

Substrate types were determined from observations by the SCUBA diver at the time of sample collection and from sediments retained on the sieves. The substrate at the 10-ft depth consisted mostly of sand and fine gravel with some silt and few rocks. The sediment sampled from all locations at the 10-ft depth contour showed these characteristics (predominantly sand). The substrate at the 20- and 30-ft depths consisted of coarse rubble, strewn with larger rocks and boulders of various sizes, with scattered pockets of clay, fine sand and gravel. Although this description is accurate for the general area, considerable differences could be encountered from specific location to location. The sediments sampled from all locations at the 20- and 30-ft depth contours were similar (predominantly rock-gravel).

B. Distribution, Species Composition and Seasonal Trends in 1973

1. Total Benthos

Results of analyses of all benthos samples are included in Appendix 8. Benthos in the vicinity of the Kewaunee Nuclear Power Plant in 1973 was comprised of 119 taxa and averaged 5232 organisms/m^2. Predominant groups collected were Oligochaeta (44%), Chironomidae (19%), Ostracoda (16%), Nematoda (9%), Tardigrada (6%), and Amphipoda (1%). The spatial abundance of benthos increased with increasing depth during each of the sampling periods with annual averages of 1551, 3023 and 10559 organisms/m^2 obtained at the 10-, 20- and 30-ft locations, respectively. The seasonal abundance of benthos was highest in September with 12999 organisms/m^2 and lowest in April with 1340 organisms/m^2 (Figure 8.1).

Benthos at the 10-ft locations (Locations 6 and 11) was consistently low in abundance throughout the year, except in May and November at Location 6 (Figure 8.2). Ostracoda comprised 63% of the benthos at Location 6 in May, which accounted for the major difference in benthos between the two 10-ft locations at that time. Rough lake conditions in November prevented sampling at Location 6. Instead, samples were taken from a greater depth (12 ft) along the same transect and where the substrate was rock-gravel rather than sand. The abundance and composition of benthos from this sample in November was more comparable to benthos collected from the rock-gravel substrate at Location 7 (the 20-ft location on the same transect) than to benthos collected from the sand substrate at Location 11 (Figure 8.2). The different substrate may have accounted for the five fold difference in total benthos between Location 11 and the location used as a substitute for Location 6 in November.

Benthos abundance was similar among the 20-ft locations during each month, except September, when the abundance at Locations 3 and 12 was approximately double that at Locations 7 and 16 (Figure 8.2). Similar abundance trends occurred among the 30-ft locations during each month. Seasonal variability of benthos at the 30-ft locations ranged from 1500 to 5000 organisms/m^2 from April through July, increased to an average of 31762/m^2 in September and declined to an average of 12581/m^2 in November (Figure 8.2).

Species diversity indices represent the "wealth" of species within

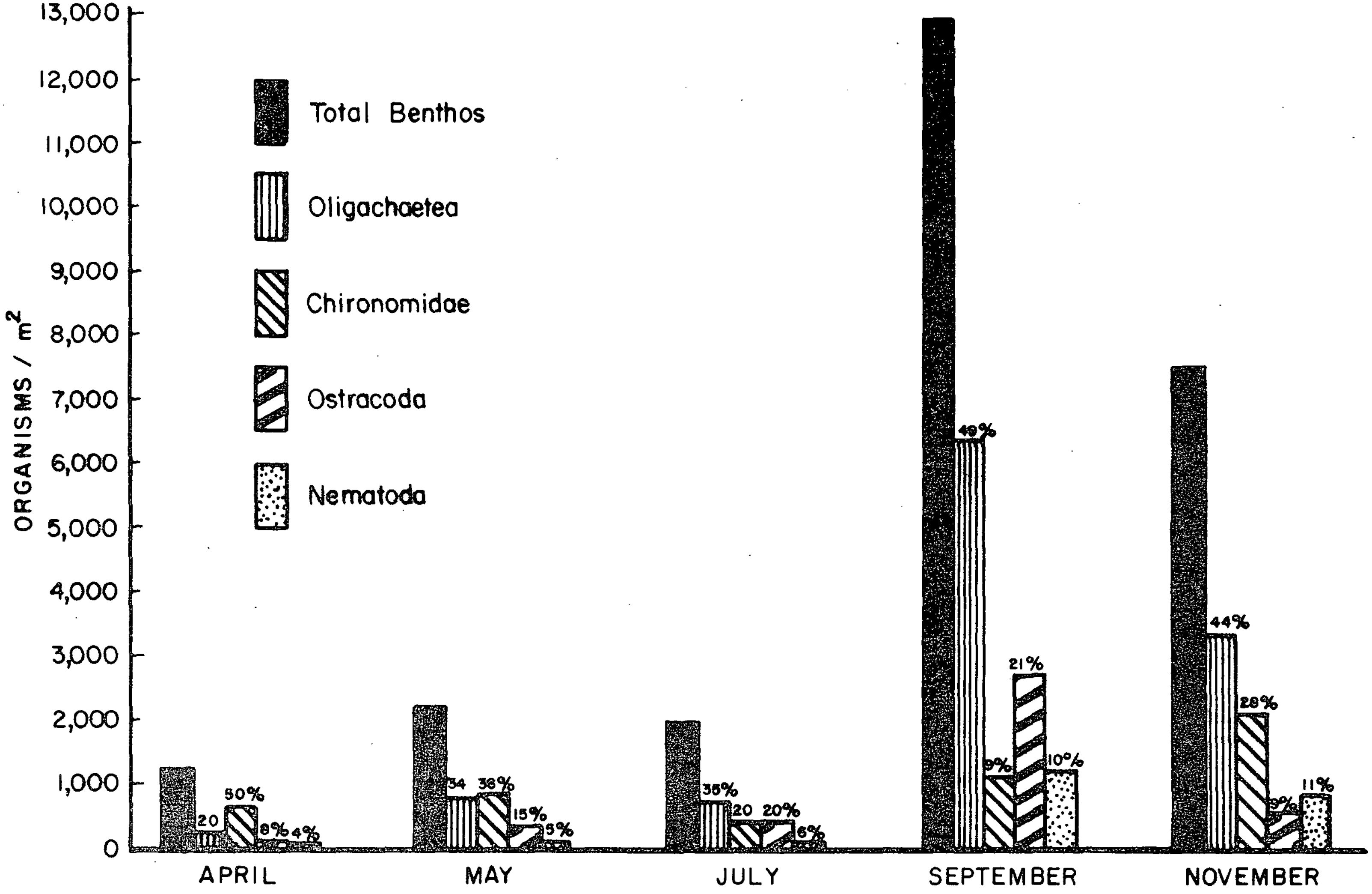

Figure 8.1. Abundances and percent composition of dominant benthic taxa collected near the Kewaunee Nuclear Power Plant in 1973.

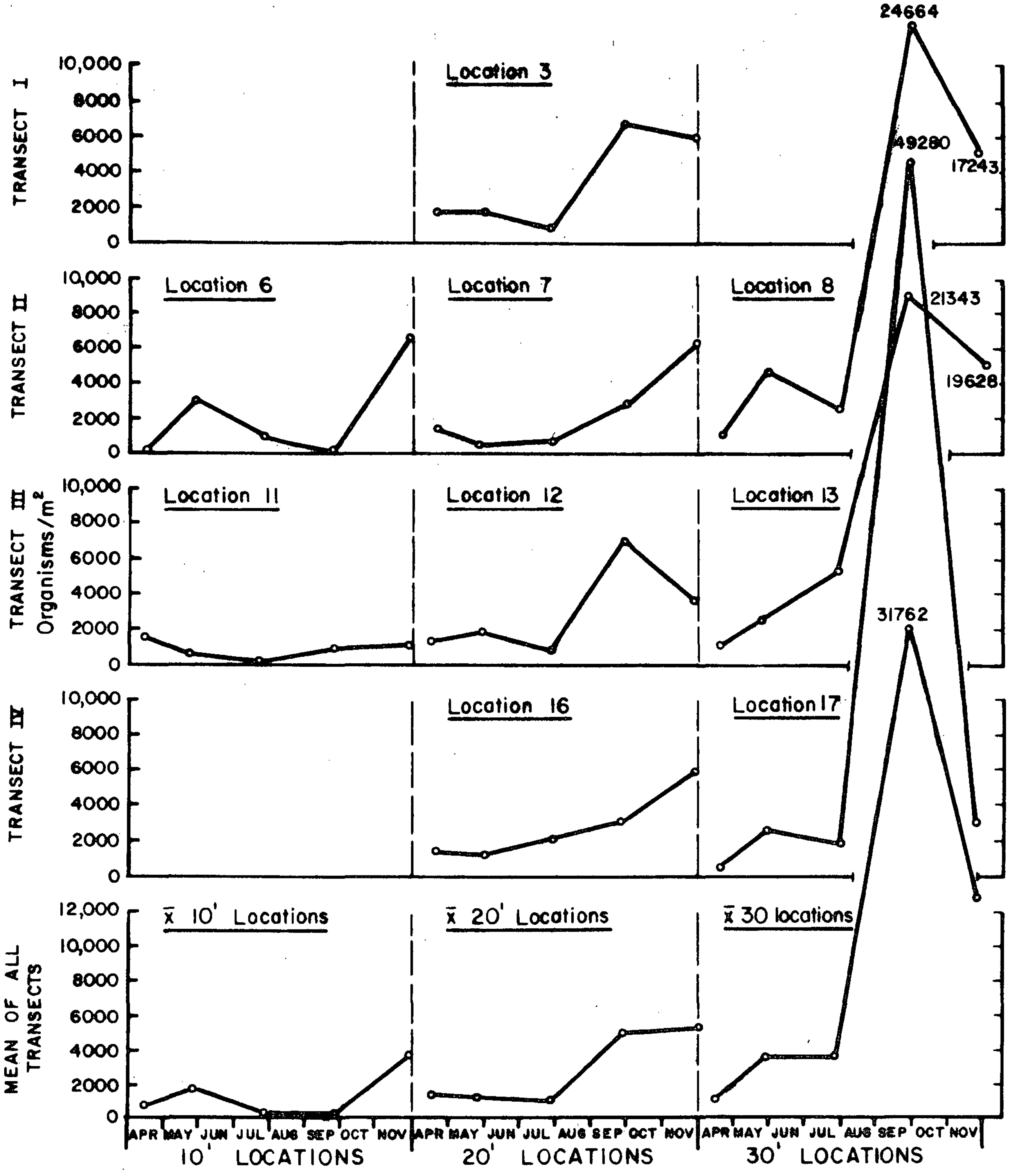

Figure 8.2. Abundance of total benthos collected near the Kewaunee Nuclear Power Plant in 1973.

a community, i.e. maximum diversity values exist when each individual belongs to a different species and minimum diversity exists when all individuals belong to the same species.

An induced stress on an environment is likely to lead to a change in the diversity of the community at the affected location. Possible effects of the thermal plume from KNPP may be reflected by a change in species diversity values between preoperational and operational benthos data.

Species diversity data are found in Appendix 8. Brillouin, Margalef, and Shannon species diversity formulae indicated the same relative temporal and spatial diversity. The following discussion of Shannon's diversity values is used as an example of the temporal and spatial variations in species diversity found in the vicinity of KNPP. Shannon species diversity values ranged from 0.772 to 2.764 at the 10-ft locations, 1.634 to 2.854 at the 20-ft locations, and 1.575 to 2.639 at the 30-ft locations (Table 8.1). Species diversity declined steadily from April (2.464) through September (1.855) and increased in November (2.498) when considering the monthly averages for all locations.

There were 29 significant differences ($P \leq 0.05$) in abundances of dominant benthic taxa out of 879 comparisons (ANOVA) (Table 8.2). Twenty significant differences occurred among locations at the 30-ft contour and nine occurred among locations at the 20-ft contour. There were 10 significant differences ($P \leq 0.05$) in 32 comparisons (Student's "t" test) between the 10-ft locations.

At the 10-ft locations, total benthos was significantly higher at Location 11 than at Location 6 in April and September, but was significantly

Table 8.1. Shannon species diversity values for benthos collected near the Kewaunee Nuclear Power Plant, 1973.

Depth (ft)	Location	April	May	July	Sept	Nov	Avg of All Months
10	6	2.378	1.591	2.335	1.242	2.205	1.950
	11	2.764	1.783	0.772	1.496	2.459	1.855
Avg 10 ft		2.571	1.687	1.528	1.369	2.332	1.670
20	3	2.429	2.639	2.148	2.580	2.602	2.480
	7	2.581	2.344	1.634	2.174	2.854	2.317
	12	2.681	2.597	2.103	2.143	2.439	2.393
	16	2.332	2.342	2.458	1.776	2.684	2.318
Avg 20 ft		2.505	2.492	2.086	2.168	2.645	2.198
30	8	2.300	2.289	2.470	1.575	2.279	2.183
	13	2.598	1.831	1.777	1.755	2.639	2.120
	17	2.111	2.221	2.460	1.950	2.319	2.212
Avg 30 ft		2.336	2.114	2.236	1.760	2.412	2.035
Avg all Locations		2.464	2.182	2.017	1.855	2.498	2.026

Table 8.2. Significant differences (P ≤ 0.05) in abundances of dominant benthic taxa among locations along each depth contour sampled in Lake Michigan near the Kewaunee Nuclear Power Plant in 1973.

Taxa	April			May			July			September			November		
	Depth Contour (Ft)			Depth Contour (Ft)			Depth Contour (Ft)			Depth Contour (Ft)			Depth Contour (Ft)		
	10	20	30	10	20	30	10	20	30	10	20	30	10	20	30
Total Benthos	11>6	N.S.	N.S.	N.S.	N.S.	N.S.	6>11	N.S.	N.S.	11>6	N.S.	N.S.	N.S.	N.S.	N.S.
Nematoda	-[a]	12>7, 16	N.S.	6>11	N.S.	N.S.	-	-	N.S.		N.S.	N.S.	N.S.	N.S.	N.S.
Oligochaeta	N.S.[b]	N.S.	N.S.	N.S.	N.S.	N.S.	6>11	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	-
Ostracoda	11>6	N.S.	N.S.	6>11	-	N.S.	-	N.S.	N.S.		N.S.	N.S.	-	N.S.	-
Gastropoda	-	N.S.	N.S.	-	N.S.	N.S.	-	N.S.	N.S.		N.S.	N.S.	-	N.S.	N.S.
Chironomidae	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	6>11	N.S.	N.S.	11>6	N.S.	N.S.	N.S.	3>7, 16	N.S.
Piquetiella michiganesis	-	-	N.S.	-	N.S.	N.S.	-	N.S.	N.S.		N.S.	N.S.	-	N.S.	-
Vejdovskyella intermedia	-	N.S.	N.S.	-	N.S.	N.S.	-	16>7	-		N.S.	N.S.	-	16>3, 12, 7	-
I. M. W. O. C.[c]	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	-	N.S.	N.S.		N.S.	N.S.	N.S.	N.S.	N.S.
Limnodrilus hoffmeisteri	-	N.S.	13>17	-	N.S.	N.S.	-	N.S.	N.S.		-	N.S.	6>11	7>3	8>17
Peloscolex superiorensis	-	N.S.	N.S.	-	N.S.	N.S.	-	-	N.S.		-	N.S.	-	-	-
Potomothrix vejdovskyi	-	N.S.	N.S.	-	N.S.	N.S.	-	N.S.	-		N.S.	N.S.	-	N.S.	N.S.
Stylodrilus heringianus	-	N.S.	N.S.	N.S.	N.S.	N.S.	-	N.S.	N.S.		N.S.	N.S.	-	3>16>12	N.S.
Gammarus pseudolimnaeus	-	N.S.	N.S.	-	N.S.	N.S.	-	N.S.	N.S.		N.S.	N.S.	N.S.	N.S.	N.S.
Heterotrissocladius sp.	-	N.S.	N.S.	-	N.S.	N.S.	-	16>7	N.S.		N.S.	N.S.	-	3>7, 12	13>8, 17
Microcricotopus sp.	N.S.	N.S.	8>17	-	N.S.	N.S.	-	-	N.S.		N.S.	N.S.	N.S.	3>12, 7, 16	N.S.
Orthocladius sp.	N.S.	N.S.	N.S.	-	N.S.	N.S.	-	N.S.	N.S.		N.S.	N.S.	N.S.	N.S.	N.S.
Parakiefferiella sp.	N.S.	N.S.	N.S.	-	N.S.	N.S.	-	N.S.	N.S.		12>7	N.S.	N.S.	N.S.	N.S.
Polypedilum (fallax	-	-		-	-	-	-	-	-		-		-	-	-
group) sp.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	-	16>7	N.S.		N.S.	N.S.	-	N.S.	N.S.
Pseudolimnaeus sp.	-	N.S.	N.S.	-	N.S.	N.S.	-	-	-		N.S.	N.S.	-	3>7	N.S.
Thienemannimyia group	-	N.S.	N.S.	-	N.S.	N.S.	-	N.S.	17>13		N.S.	N.S.	-	N.S.	13>8

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[a] Insufficient data.
[b] No significant difference.
[c] Unidentifiable immature tubificidae without capilliform chaetae.

lower in July (Table 8.2). There were no significant differences in total benthic abundance among locations at either the 20- or the 30-ft contour.

No patterns could be detected for the differences in abundance that were significant among dominant benthic taxa for a given depth. Significant differences may have occurred because of the variability of the substrates sampled at each specific location. Generally the substrates were similar along each depth contour, but benthos quality and quantity may have varied between samples depending on whether rocks, sand, silt, or clay were sampled or due to natural variability from location to location of apparently similar substrates.

2. Oligochaeta

Oligochaetes averaged 2294 organisms/m^2 and represented 44% of the benthos collected near the KNPP in 1973. Oligochaetes were least abundant from April through July when their standing crop ranged from 269 to 784/m^2 (Figure 8.1). They averaged 6373 and 3332/m^2 in September and November, respectively. Both abundance of Oligochaeta and the proportion of the total benthos which they represented followed the same trends seasonally (Figure 8.1).

Numbers of oligochaetes increased with depth, ranging from an average of 485/m^2 along the 10-ft depth contour to 4648/m^2 along the 30-ft depth contour. The greatest number of oligochaetes collected was 19951/m^2 at Location 17 (a location at the 30-ft depth) in September (Figure 8.3).

a. Naididae

Naididae averaged 1044 organisms/m^2 and represented 46% of the oligochaetes. Naidids were composed almost entirely of Vejdovskyella

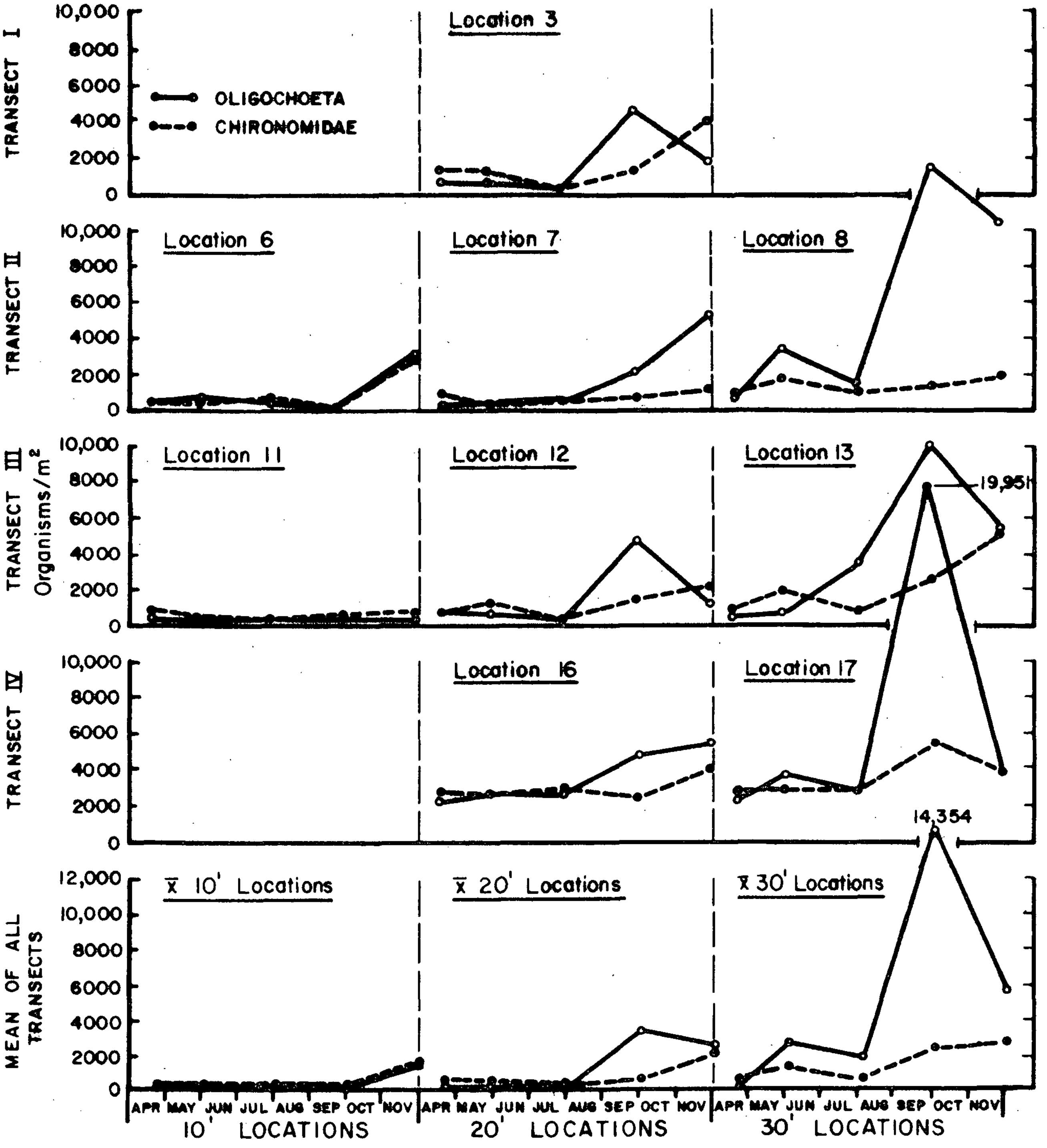

Figure 8.3. Abundance of Oligochaeta and Chironomidae collected near the Kewaunee Nuclear Power Plant in 1973.

intermedia which averaged 104, 440, and 2550 organisms/m^2 for the 10-, 20- and 30-ft locations, respectively, increasing in abundance with increasing depth (Figure 8.4). Vejdovskyella intermedia was most abundant in September when it averaged nearly nine times more individuals per square meter than for any other month (Table 8.3). Other abundant naidids were Nais behningi, Paranais frici, Stylaria lacustris and Uncinais uncinata, all of which attained their greatest abundance in either September or November. This increase during the fall season indicated that naidids in the vicinity of the KNPP reproduced primarily in the fall, which correlates closely to the time of greatest sexual activity of naidids in southern Lake Michigan as reported by Hiltunen (1967). Many of the S. lacustris and a few of the Nais sp. collected in September were sexually mature. Many zooids (young individuals formed by the reproductive process of budding) of V. intermedia were also observed in September.

Little is known about the ecology of naidids. The high abundance of V. intermedia near the KNPP, especially in relation to the numbers of other naidid species noted (both in 1972 and 1973), does not compare with naidid populations reported from southern Lake Michigan where Uncinais uncinata and Piguetiella michiganensis were predominant (Hiltunen 1967; Industrial BIO-TEST Laboratories, Inc. 1972a and b).

b. Tubificidae

Tubificidae averaged 1091 organisms/m^2 and composed 48% of the oligochaetes. Fifteen species of tubificids were collected (Table 8.4). They were divided among two groups, those with and those without capilliform chaetae.

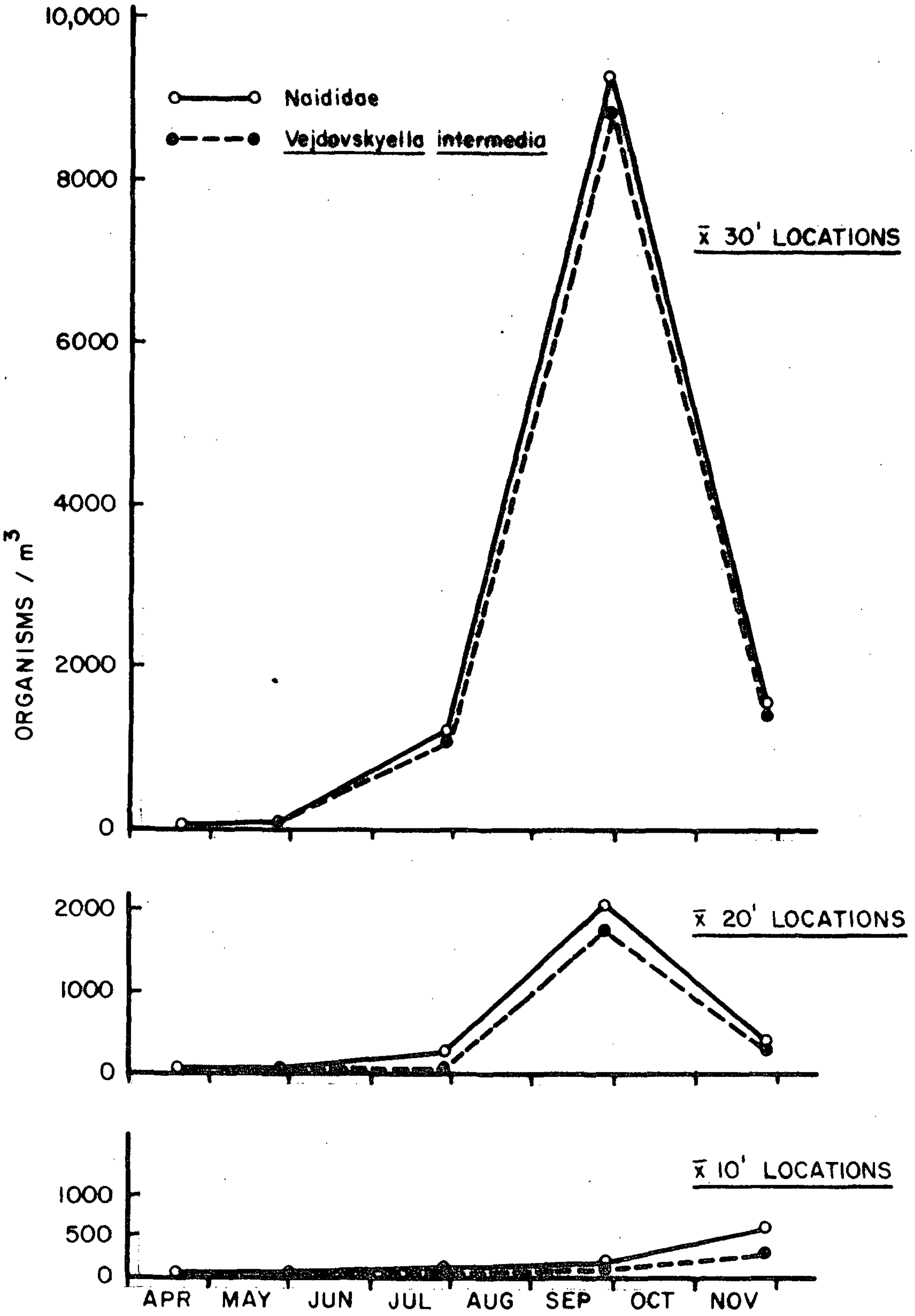

Figure 8.4. Abundance of Naididae and Vejdovskyella intermedia collected near the Kewaunee Nuclear Power Plant in 1973.

Table 8.3. Average number of organisms/m^2 for Naididae species collected in Lake Michigan near the Kewaunee Nuclear Power Plant, 1973.

	Sampling Months				
Species	April	May	July	September	November
Chaetogastor diaphanus	1	0	11	7	1
Nais behningi	0	0	0	37	65
Nais bretcheri	0	0	0	19	4
Nais sp.	1	0	0	1	1
Paranais frici	0	0	0	55	49
Paranais litoralis	1	5	0	1	0
Piguetiella michiganensis	1	1	3	11	2
Slavina appendiculata	1	0	0	1	1
Stylaria fossularis	1	0	0	0	0
Stylaria lacustris	0	4	44	97	1
Uncinais uncinata	0	0	17	16	1
Vejdovskyella intermedia	12	57	430	3781	282
Total Naididae	15	82	504	4115	823

Table 8.4. Average number of organisms/m^2 for Tubificidae species collected in Lake Michigan near the Kewaunee Nuclear Power Plant, 1973.

Species	April	May	July	September	November
Ilyodrilus templetoni	0	19	1	1	6
Limnodrilus angustipenis	0	1	0	0	5
L. claparedianus	0	0	0	0	5
L. hoffmeisteri	12	80	19	15	100
L. hoffmeisteri (variant)	1	4	3	1	15
L. profundicola	0	4	1	1	1
L. spiralis	1	10	0	2	31
L. udekemianus	1	1	1	2	5
Peloscolex freyi	0	0	1	0	0
P. multisetosus multisetosus	0	1	0	0	1
P. superiorensis	6	14	1	1	0
Potamothrix moldaviensis	1	9	5	31	114
P. vejdovskyi	15	16	18	45	40
Tubifex ignotus	0	0	0	1	0
T. Tubifex	1	25	5	10	16
Unidentifiable Immatures					
with capilliform chaetae	15	54	23	476	409
without capilliform chaetae	117	309	122	1503	1794
Total Tubificidae	171	566	194	2176	2344

Limnodrilus angustipenis, Limnodrilus claparedianus, Limnodrilus hoffmeisteri (variant), Limnodrilus profundicola, Limnodrilus spiralis, Potamothrix moldaviensis and Peloscolex freyi are species without capilliform chaetae. Ilyodrilus templetoni, Peloscolex superiorensis and Tubifex tubifex are species with capilliform chaetae. All of the above species must be sexually mature to be identified to the species level. The immature individuals of these two groups were classified as unidentifiable immature Tubificidae "with" or "without" capilliform chaetae. The remaining tubificids, Limnodrilus udekemianus, Peloscolex multisetosus multisetosus, Potamothrix vejdovskyi and Tubifex ignotus, were identifiable in all stages of development; therefore, their abundances were not directly comparable to the other tubificid species whose numbers represented only mature individuals.

Unidentifiable immature tubificids represented 85% of the Tubificidae collected and their abundance increased with increasing depth (Figure 8.5). Both groups of immatures attained their greatest numbers at the 30-ft depth locations in September; however, maximum numbers did not occur at the 10- and 20- ft locations until November. Most of the unidentifiable immatures without capilliform chaetae were probably L. hoffmeisteri and P. moldaviensis, based upon the abundances of mature specimens of these tubificids observed in the benthos. The presence of L. hoffmeisteri in the vicinity of the KNPP is not surprising, since it is cosmopolitan and is abundant in clean water situations as well as organically polluted areas (Brinkhurst et al. 1968).

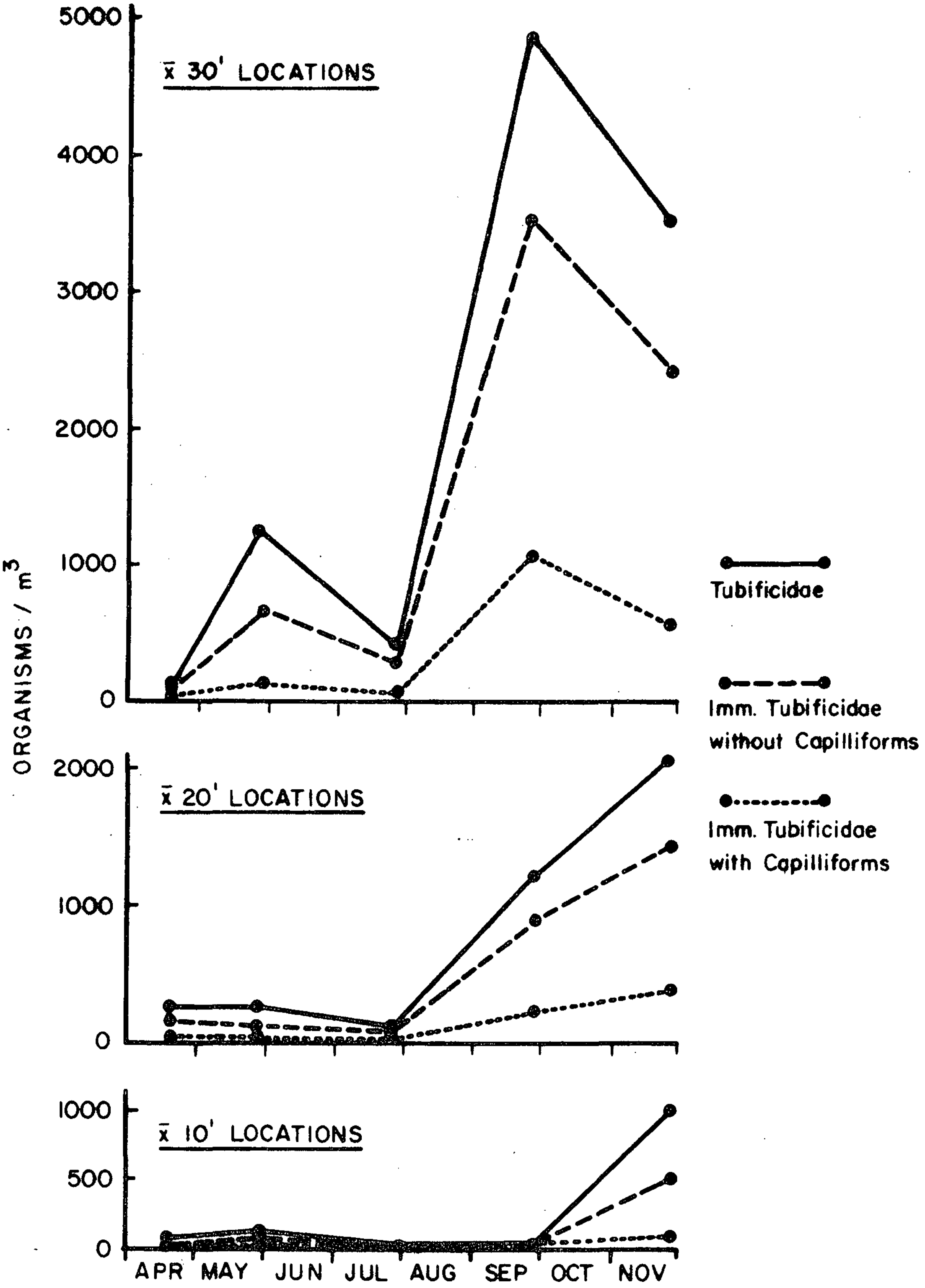

Figure 8.5. Abundance of Tubificidae and immature Tubificidae collected near the Kewaunee Nuclear Power Plant in 1973.

An increased rate of reproduction for L. hoffmeisteri was found to be related to increased temperature, both in laboratory experiments, and in natural field studies conducted on a thermal effluent from a power plant on the River Trent in England (Aston 1973). The standing crop of L. hoffmeisteri and its relative abundance to other tubificid species will be a useful guide in detecting any operational effect in the immediate vicinity of the KNPP discharge.

The majority of unidentifiable immature tubificids with capilliform chaetae belonged to T. tubifex. The remaining immatures of this group were I. templetoni and P. superiorensis. Tubifex tubifex and I. templetoni, along with L. hoffmeisteri and P. m. multisetosus were the only species classified by Hiltunen (1967) as saprophiles (widely distributed and not especially abundant in clean waters, but abundant in polluted waters).

Of the four tubificids which were identifiable at all stages of maturity (L. udekemianus, P. m. multisetosus, P. vejdovskyi, and T. ignotus), P. vejdovskyi was the most abundant (Table 8.4). The abundance of P. vejdovskyi was relatively low from April through July (15 to 18/m^2), then increased in September and November (40 to 45/m^2). Limnodrilus udekemianus, P. m. multisetosus and T. ignotus were rare and no seasonal trends could be detected.

c. Lumbriculidae

The only other prominant family of oligochaetes collected during the study was Lumbriculidae, which was represented by a single species, Stylodrilus heringianus. Stylodrilus heringianus averaged 82 organisms/m^2

and represented 4% of the oligochaetes for all locations throughout the sampling period. The average abundance of S. heringianus generally increased with depth. A peak in abundance at all three depths occurred in the spring and again in late fall. This species is common throughout Lake Michigan, and is the predominant oligochaete in the profundal zone.

d. Other Oligochaete Families

The other families of oligochaetes found in the vicinity of the KNPP were Enchytraeidae and Glossoscolecidae. Enchytraeidae increased in abundance with increased depth, was present mainly when the water was cooler in spring and fall, and was rarely observed in the summer. Enchytraeidids were present in 30 of the 45 samples collected, but never accounted for more than 80 organisms/m^2. Glossoscolecidae was represented by a single specimen of Sparganophilus sp.

Those organisms referred to as Branchiobdellidae (Oligochaeta) in Appendix 8 have been elevated to their own class, Branchiobdellida (Brinkhurst and Jameison 1971). Branchiobdellida closely resemble oligochaetes and are parasites on crayfish. Few Branchiobdellida were collected and their greatest abundance, 64 organisms/m^2, occurred in a sample in which a crayfish was also collected.

3. Chironomidae

Chironomidae (midge fly) larvae averaged 1010 individuals/m^2 and made up 19% of the benthos collected in the vicinity of the KNPP in 1973. They were represented by 37 taxa including 15 Chironominae, 11 Orthocladiinae, 9 Tanypodinae, and 2 Diamesinae. Chironomidae were most abundant in November and least abundant in July with an average of 2127 and 403 larvae/m^2, respectively (Figure 8.1). The chironomid portion of the total benthos declined steadily from a high of 50% in April to a low of 9% in September and then increased again to 28% in November (Figure 8.1). Chironomids were most abundant at the 30-ft locations and least abundant at the 10-ft locations in all months (Figure 8.3).

a. Orthocladiinae

Orthocladiinae was the most abundant subfamily of Chironomidae, comprising 43% of the midges collected in 1973 (Table 8.5). Orthocladiinae was most abundant along the 30-ft contour and least abundant along the 10-ft contour. Orthocladiinae was most abundant in May and least abundant in September (Table 8.5).

Parakiefferiella sp. was the most abundant chironomid with an average of 364 larvae/m^2. This taxon was most abundant in May and least abundant in July averaging 639 and 169 larvae/m^2, respectively (Table 8.6). Parakiefferiella sp. was most abundant at the 30-ft locations and least abundant at the 10-ft locations in 1973. Little is known at the present time regarding its ecological requirements.

Heterotrissocladius sp. was common in Lake Michigan in the vicinity of the KNPP and abundances increased with increasing depth over all months. This taxon was least abundant in May (12/m^2) and steadily increased thereafter, with the highest abundance occurring in November (181/m^2)

Table 8.5. Average abundance (No./m^2) of Chironomidae subfamilies and the percent they represented to total Chironomidae collected near the Kewaunee Nuclear Power Plant, 1973.

Subfamily	Mean of all Locations					Mean for All Months	Mean of all Locations		
	Apr	May	Jul	Sept	Nov		10 ft Locations	20 ft Locations	30 ft Locations
Orthocladiinae	56% 447/m^2	53% 753/m^2	60% 365/m^2	28% 323/m^2	34% 662/m^2	43% 599/m^2	38% 112/m^2	41% 220/m^2	33% 266/m^2
Chironominae	39% 314/m^2	40% 568/m^2	23% 142/m^2	53% 601/m^2	39% 766/m^2	40% 239/m^2	44% 133/m^2	42% 223/m^2	44% 355/m^2
Tanypodinae	3% 27/m^2	6% 83/m^2	15% 93/m^2	11% 124/m^2	19% 382/m^2	12% 141/m^2	10% 31/m^2	13% 66/m^2	18% 145/m^2
Diamesinae	1% 6.5/m^2	<1% 8/m^2	1% 6/m^2	8% 94/m^2	7% 145/m^2	4% 521/m^2	8% 23/m^2	4% 20/m^2	6% 45/m^2

Table 8.6. Average number/m^2 of predominant Chironomidae taxa collected in Lake Michigan near the Kewaunee Nuclear Power Plant in 1973.

Species	Mean of all Locations				
	April	May	July	September	November
Corynoneura sp.	0	3	4	0	0
Cryptochironomus sp.	1	5	2	28	40
Heterotrissocladius sp.	23	12	74	89	181
Microcricotopus sp.	9	67	40	1	4
Micropsectra sp.	4	0	6	1	33
Microtendipes sp.	29	22	1	192	313
Monodiamesa sp.	6	8	6	88	138
Near Demicryptochironomus	0	0	0	35	1
Paracladopelma sp.	10	5	10	52	119
Parakiefferiella sp.	238	639	179	185	580
Polypedilum (Fallax) sp.	108	474	37	75	69
Polypedilum (Tripodura) sp.	1	42	67	103	97
Potthastia sp.	1	0	1	6	7
Procladius (Procladius) sp.	0	0	0	11	48
Procladius (Psilotanypus) sp.	0	0	1	28	102
Synorthocladius sp.	38	9	2	0	4
Tanytarsus sp.	3	3	6	28	27
Thienemanniella sp.	0	0	5	15	7
Thienemannimyia group.	28	83	92	85	232

(Table 8.6). Heterotrissocladius sp. is a cold stenothermal organism commonly found in the profundal zones of the Great Lakes (Brinkhurst et al. 1968).

Microcricotopus sp. was the only chironomid whose abundance decreased with increased depth. It averaged 132, 98 and 44 larvae/m^2 for the 10-, 20- and 30-ft locations, respectively. This taxon was most abundant in May (67 larvae/m^2) and least abundant in September (1 larvae/m^2) (Table 8.6). The abundance of Synorthocladius sp. decreased steadily from a high of 38 larvae/m^2 in April to no larvae collected in September (Table 8.6). Synorthocladius sp. abundance was lowest at the 30-ft locations and highest at the 20-ft locations.

Corynoneura sp. and Thienemanniella sp. were the only representatives of the tribe Corynoneurini, subfamily Orthocladiinae, in the vicinity of the KNPP in 1973. Generally Corynoneurini larvae are free-living and very good swimmers (Chernovskii 1949). Corynoneura sp. was collected only in May and July and was not present at any of the 10-ft locations. Corynoneura sp. was most abundant in July averaging 4 larvae/m^2 (Table 8.6). Thienemanniella sp was collected only in July, September and November and was most abundant at the locations with a rock-gravel substrate. It was most abundant in September averaging 15 larvae/m^2. This taxon was not collected in the 1972 preoperational study at KNPP.

b. Chironominae

Chironominae was second in abundance to Orthocladiinae in

1973 (Table 8.5). Chironominae were most abundant in November but made up the greatest percentage of the chironomid populations in September. Chironominae were most abundant at the 30-ft locations where they made up 44% of the midge assemblage.

Tanytarsus sp. and Micropsectra sp. are tubicolous (tube dwelling) members of the subfamily Chironomidae, tribe Tanytarsini. Abundance of both genera was greatest at the 30-ft locations and lowest at the 10-ft locations. Micropsectra sp. was most abundant in November (33 larvae/m^2) and least abundant in May when no larvae were collected (Table 8.6). Tanytarsus sp. was most abundant in September (28 larvae/m^2) and least abundant in April and May (3 larvae/m^2). Both have been previously reported from the profundal benthos of Lake Erie (eastern basin), Lake Ontario and Georgian Bay, and were associated with cold stenothermic conditions in the Great Lakes (Brinkhurst et al. 1968). Generally, Tanytarsini are detrito-phytophagic, feeding on organic detritus and algae (Chernovskii 1949).

Microtendipes sp. is a tubicolous, detrito-phytophagic member of the subfamily Chironominae. It was most abundant at the 20-ft locations and least abundant at the 10-ft locations, averaging 150 and 37 larvae/m^2, respectively. Microtendipes sp. was most abundant in November and least abundant in July with 313 and 1 larvae/m^2, respectively (Table 8.6).

Paracladopelma sp. was most abundant at the 10-ft locations. It's population was greatest in November (119 larvae/m^2) and least abundant in May (5 larvae/m^2) (Table 8.6). Mozley and Garcia (1972) classified

Paracladopelma sp. as a psammobiont which wanders freely between the sand grains of the "Shallow Zone" in the coastal waters of southeastern Lake Michigan.

Cryptochironomus sp. larvae are predaceous, feeding on oligochaetes and midge larvae (Chernovskii 1949). Mozley and Garcia (1972) included this genus in a group of taxa characterizing the "Shallow Zone" of southeastern Lake Michigan. Cryptochironomus sp. abundance increased with increasing depth in the vicinity of KNPP being most abundant in November and least abundant in April with 40 and 1 larvae/m^2, respectively (Table 8.6).

"Near" Demicryptochironomus resembles the genus Demicryptochironomus but "near" Demicryptochironomus has antennae with five rather than seven segments. "Near" Demicryptochironomus sp. was collected only in September and November and was most abundant at the 10-ft locations.

Polypedilum was represented by two groups of species, Fallax and Tripodura. Polypedilum (Fallax) sp. was most abundant at the 30-ft locations and least abundant at the 10-ft locations. Polypedilum (Tripodura) sp. was least abundant at the 20-ft locations and most abundant at the 30-ft locations. Polypedilum (Tripodura) sp. was more abundant than Polypedilum (Fallax) sp. in 1973. Polypedilum (Fallax) sp. was most abundant in May and least abundant in September, while Polypedilum (Tripodura) sp. was most abundant in September and least abundant in April (Table 8.6).

c. Tanypodinae

Tanypodinae made up 12% of the Chironomidae in 1973 (Table 8.5) and was most abundant at the 30-ft locations. Ablabesmya sp., Procladius sp., and the Thienemannimyia group were the only Tanypodinae collected in 1973. Tanypodinae are carnivorous larvae that actively pursue their prey, which may include other Chironomidae larvae (Chernovskii 1949). Only one Ablabesmyia sp. larvae was collected in 1973.

The genus Procladius is subdivided into two groups, Procladius (Psilotanypus) sp. and Procladius (Procladius) sp. Both Procladius groups were collected primarily in September and November, being most abundant in November (Table 8.6). Procladius (Psilotanypus) sp. was the most abundant of the two groups. Both groups were collected from all depth contours, but were most numerous at the 30-ft locations. Chernovskii (1949) noted that larvae of the genus Procladius have a wide distribution ranging from the deepest region of a lake almost to shore. Brinkhurst et al. (1968) recognized Procladius in the Great Lakes as a cosmopolitan taxon.

The Thienemannimyia group is a taxonomic category of several genera which cannot be further identified by the examination of larval characters. The Thienemannimyia group was the most prevalent member of the Tanypodinae in 1973. Largest populations occurred in November with an average of 232 larvae/m^2 for all locations in the study area (Table 8.6). Thienemannimyia group was most abundant along the 30-ft contour and least abundant along the 10-ft contour.

d. Diamesinae

Diamesinae comprised 4% of the total Chironomidae in 1973 (Table 8.5). Their populations were largest in November, but comprised a greater percentage of the Chironomidae in September. Diamesinae were most abundant at the 30-ft locations (Table 8.5).

Potthastia sp. and Monodiamesa sp. were the only genera of Diamesinae collected. Potthastia sp. increased in abundance with increased depth and Monodiamesa sp. was most numerous at the 30-ft locations. Both of these genera were most abundant in November (Table 8.6). Brinkhurst et al. (1968) described Potthastia as being a cold stenothermic organism. He also characterized both genera as common components of the profundal region of the Great Lakes.

4. Other Benthos

Pontoporeia affinis is considered to be one of the most abundant benthic organisms in Lake Michigan (Eggleton 1936 and 1937; Industrial BIO-TEST Laboratories, Inc. 1972a and b; Robertson and Alley 1966; Rains 1971); however, P. affinis was scarce near the KNPP in 1973 averaging less than $1/m^2$. The absence of a suitable substrate in the study area might explain the scarcity of this species. Alley (1968) noted that P. affinis was a burrowing amphipod which was most abundant in silty-sand substrates and least abundant in hard bottom substrates. Marzolf (1965) reported that P. affinis was scarce in Grand Traverse Bay, Lake Michigan, where the substrate was clean, coarse sand, strewn with large boulders. Such substrate is similar to that in the vicinity of KNPP.

Gammarus pseudolimnaeus was the most abundant amphipod observed, averaging 4 organisms/m^2. It was most abundant in November at the 20-ft locations. High population densities of G. pseudolimnaeus have been associated with substrates similar to those found near the KNPP (Rees 1972).

Gastropods averaged 21 organisms/m^2 in 1973 and were lower in abundance than in 1972. Gastropod populations were highest in April (38/m^2) and lowest in July (3/m^2), and generally increased with increasing depth.

Nematoda averaged 476 organisms/m^2 and composed 9% of the total benthos. Populations were highest in September (1235/m^2) and lowest in April (51/m^2) (Figure 8.1), and generally increased with increasing depth.

Ostracoda was most abundant in September (2728/m^2) and least abundant in April (107/m^2) (Figure 8.1). Ostracoda was most abundant at the 30-ft locations (2111/m^2) and least abundant at the 20-ft locations (198/m^2).

Further identification of the order Ostracoda necessitates careful dissections and individual glass slide mounts of adult specimens. The time and expense required to specifically identify these organisms was not deemed worthy of the amount of information that would be gained. Generally ostracods are tolerant of a wide range of ecological factors which are usually regarded as limiting for entomostracans (Pennak 1953).

Sphaeriidae was the only Pelecypoda collected and was not abundant in 1973. Its abundance ranged from 0 to 83/m^2.

C. Comparison of 1972 and 1973 Benthos Data

The total benthos assemblage averaged 4653 organisms/m^2 in 1972 and

19752/m^2 in 1973 (30 and 100 mesh data combined). The abundance of total benthos and various taxa was significantly higher ($P \leq 0.05$) in 1973 than in 1972 in 91 of 102 statistical comparisons (Table 8.7). It is unlikely that natural variability accounted for the differences noted between 1972 and 1973 data. The significantly higher numbers in 1973 may have been due in part to the smaller area sampled (1/8 sq m) for each replicate which allowed the diver to more thoroughly sample the area. Also, with the smaller areas sampled in 1973 the number of organisms recruited from outside the sampling area may have represented a greater proportion of organisms in the sample, since with a smaller sampling area the ratio of the perimeter to the area sampled increases Because of the smaller areas sampled in 1973 a larger conversion factor was necessary for converting data to number of organisms per square meter. This further increased the importance of recruitment when comparing data enumerated as No/m^2.

Thirty-eight taxa were collected in 1973 that were not collected in 1972 (Table 8.8). Fifteen of the 38 new taxa were oligochaetes and 12 were chironomi Paranais littoralis, Limnodrilus claparedianus, Limnodrilus profundicola, Limnodrilus udekemianus and Slavina appendiculata were the most abundant new oligochaete taxa. Near Demicryptochironomus sp., Procladius (Procladius) sp. and Thienemanniella sp. were the most abundant new chironomid taxa. Paludicella articulata, Fredericella sp. and Cristatella mucedo were present in 1972 but were listed as Bryozoa.

Fourteen taxa were reported in 1972 that were not present in the

Table 8.7 Comparisons between 1972 and 1973 abundances (No./m^2) of total benthos and major taxonomic groups collected near the Kewaunee Power Plant.

Sampling Periods and Taxon	Locations and Years													
	7		8		11		12		13		16		17	
	1972	1973	1972	1973	1972	1973	1972	1973	1972	1973	1972	1973	1972	1973
1 Aug 1972 vs. 24 Jul 1973 Taxon														
Total Benthos	677	5,551*	639	8,410	174	935	2,141	10,388*	- b/	-	2,888	17,168*	1929	29,841*
Chironomidae	147	398*	137	1,245*	72	134	351	513*	- b/	-	836	1,653*	84	1,125*
Oligochaeta	43	697*	55	16,623*	98NS	83	275	1,266	- b/	-	900	3,080*	846	3,882*
Ostracoda	436	3,235*	283	30,400	0 a/	147	1,390	5,944*	- b/	-	628	6,723*	602	13,901*
Nematoda	0 a/	701	23	18,691*	0 a/	483	3 a/	1,285	- b/	-	16	2,323*	28	7,179*
Vejdovskyella intermedia	4 a/	163	0 a/	4,067	3 a/	43	15	683*	- b/	-	20	955*	6 a/	2,840
26 Sept 1972 vs. 28 Sept 1973 Taxon														
Total Benthos	5,580	28,484*	4,396	52,329*	494	3,273*	3,244	23,151	- b/	-	6,316	44,140*	1,282	124,665*
Chironomidae	376	2,246*	116	2,115*	204	656*	1,242	3,842*	- b/	-	1,080	4,903*	276	7,825*
Oligochaeta	388	12,409*	1,824	21,599*	132	390*	1,234 NS	1,227	- b/	-	2,006	25,757*	888	40,009*
Ostracoda	4,378	3,776*	1,886	9,920*	124 NS	123	-c/	3,061	- b/	-	2,024	4,555*	0 a/	22,061
Nematoda	2 a/	5,093	22	14,248*	32	1,195*	-c/	856	- b/	-	1,066	2,211*	48	19,101*
Vejdovskyella intermedia	328	9,187*	726	9,392*	96	349*	1,072	9,936*	- b/	-	1,684	24,325*	824	32,951*
7 Nov 1972 vs. 16 Nov 1973 Taxon														
Total Benthos	3,158	19,186*	5,314	129,710*	312	10,230*	1,376	13,319*	8,722	30,492*	14,860*	13,694	14,590*	10,994
Chironomidae	1,198	2,457*	2,026	3,557*	194	2,939*	1,268	6,004*	2,802	6,926*	5,840*	2,651	2,538*	1,806
Oligochaeta	862	9,830*	2,212	44,969*	30	3,792*	1,070	3,101*	1,460	7,275*	2,216	6,075	5,056NS	4,947
Ostracoda	246	4,475*	614	10,749*	32	1,684*	120	2,131*	3,368	9,659*	5,604*	1,461	4,080*	1,147
Nematoda	580	1,205*	132	63,269*	30	749*	94	587*	542	2,312	362	1,371*	2,492NS	2,520
Vejdovskyella intermedia	768	4,141*	1,780	25,048*	16	3,053*	116	1,950*	628	2,891*	1,936	3,507*	2,800*	1,480

N.S.	No significant difference
*	Significant Difference ($P \leq 0.05$)
a/	Insufficient data for statistical analysis
b/	No sample taken
c/	Taxon present but not counted

Table 8.8. Benthos taxa collected in 1973 which were not reported in 1972 near the Kewaunee Nuclear Power Plant.

- Porifera
  - *Spongilla fragilis*
- Gastropoda
  - *Lymnaea auricularia*
  - *Valvata tricarinata*
- Oligochaeta
  - Glossoscolecidae
    - *Sparganophilus* sp.
  - Naididae
    - *Nais behningi*
    - *N. bretscheri*
    - *Paranais frici*
    - *P. littoralis*
    - *Slavina appendiculata*
    - *Stylaria fossularis*
  - Tubificidae
    - *Limnodrilus claparedianus*
    - *L. profundicola*
    - *L. udekemianus*
    - *Peloscolex freyi*
    - *P. multisetosus longidentus*
    - *P. multisetosus multisetosus*
    - *P. superiorensis*
    - *Tubifex ignotus*
- Branchiobdellida
- Hirudinea
  - *Dina parva*
- Insecta
  - Collembola
  - Plecoptera
  - Ephemeroptera
    - Baetidae
  - Diptera
    - Psychodidae
      - *Psychoda* sp.
    - Chironomidae
      - *Ablabesmyia* sp.
      - *Clinotanypus* sp.
      - *Cryptocladopelma* sp.
      - *Demicryptochironomus* sp.
      - near *Demicryptochironomus* s
      - *Endochironomus* sp.
      - *Paratanytarsus* sp.
      - *Phaenopsectra* (Tribelos) sp.
      - *Procladius* (Procladius) sp.
      - *Psectrocladius* sp.
      - *Thienemanniella* sp.
      - *Trissocladius* sp.

vicinity of the KNPP in 1973 (Table 8.9). None of these taxa represented more than 1% of the total benthos in 1972.

It is probable that the area in the vicinity of the KNPP was more thoroughly sampled in 1973 since 135 samples were collected as compared to 30 in 1972. Also, Locations 3 and 6 were new locations added and sampled in 1973 for the first time. These factors probably accounted for the increased number of taxa in 1973.

Table 8.9. Benthos taxa collected in 1972 which were not reported in 1973 near the Kewaunee Nuclear Power Plant.

- Gastropoda
  - Hydrobiidae
    - *Bulimus tentaculata*
  - Planorbidae
    - *Gyralus deflectus*
  - Valvatidae
    - *Valvata perdepressa*
- Oligochaeta
  - Naididae
    - *Nais elinguis*
- Hirudinea
  - Piscicolidae
    - *Piscicola geometra*
- Insecta
  - Trichoptera
    - Leptoceridae
      - *Leptocella* sp.
      - *Trianoides* sp.
  - Diptera
    - Chironomidae
      - *Acricotopus* sp.
      - near *Constempellina* sp.
      - *Cricotopus* sp.
      - *Paralauterborniella* sp.
      - *Paratendipes* sp.
      - *Rheotanytarsus* sp.
      - near *Sympotthastia* sp.

IV. Summary and Conclusions

1. Abundance of benthos increased with increasing depth. Total populations were largest in September when 12992 organisms/m^2 were recorded, and smallest in April when 1340 organisms/m^2 were recorded.

2. There were few significant ($P \leq 0.05$) differences among benthic populations at locations on the same depth contour.

3. Oligochaetes represented 44% of the benthic community. Naididae accounted for 46% of the Oligochaeta and was comprised almost entirely of Vejdovskyella intermedia. Tubificidae represented 48% of the oligochaetes and Limnodrilus hoffmeisteri and Potamothrix moldaviensis were the most numerous tubificids.

4. Chironomidae represented 19% of the benthos and consisted primarily of Orthocladiinae (43%) and Chironominae (40%).

5. Gammarus pseudolimnaeus was the most abundant amphipod collected in the vicinity of Kewaunee Nuclear Power Plant.

6. Benthos averaged 4653 organisms/m^2 in 1972 and 19752/m^2 in 1973. The increased abundance may have been due to changes in sampling methods which included sampling a smaller area which improved sampling efficiency or increased the proportion of recruited organisms.

7. Thirty-eight taxa collected in 1973 were not collected in 1972. This was probably due to the sampling of a greater number of habitat types in 1973.

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Chapter 9

FISH POPULATION AND LIFE HISTORY

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PREOPERATIONAL THERMAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR KEWAUNEE NUCLEAR POWER PLANT

THIRD ANNUAL REPORT
January-December 1973

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Chapter 9

FISH POPULATION AND LIFE HISTORY

Larry LaJeone

I. Introduction

The purpose of this report is to discuss the continuing collection in 1973 of preoperational baseline data on fish population and life history in the vicinity of the Kewaunee Nuclear Power Plant (KNPP).

The specific study objectives were:

1. to analyze the seasonal distribution and movement of fish inhabiting certain areas in the vicinity of KNPP and especially adjacent to the Plant intake and discharge;
2. to determine what segments of the life history of fishes present are being completed in the study area;
3. to determine the composition and relative abundance of fish species collected; and
4. to compare the results of the 1973 study with results collected during the previous preoperational monitoring in 1971 and 1972.

II. Field and Analytical Procedures

Fish sampling locations in Lake Michigan were the same as those established in 1972 (Industrial BIO-TEST Laboratories, Inc. 1973). Fish were collected by gill netting at Locations A, B and C; by minnow seining at Locations 5, 9 and 19; and fish eggs and larvae were collected by pumping at Locations 6, 7, 10, 11, 20 and 21 (Figure 1, Introduction). An additional sampling location was established in the forebay of the Plant for collection of fish eggs and larvae entrained in the intake.

Fish were sampled 14 April, 23 May, 27 June, 25 July, 29 August, 27 September, 24 October and 14 November using gill nets. Gill net specifications were similar to those used in the 1972 study with the exception of the addition of a 50-foot panel of 1 1/2" stretch mesh, in order to facilitate collection of smaller species of fish and juveniles that might evade larger meshes, or be unavailable to shoreline seining. The following four panels were used in each set:

Net Length (feet)	Stretched Mesh Size (inches)	Twine Size	Phase Measure (inches)	Ties Between Leads	No. of Mesh on Each Tie	No. of Leads Per Net	Mesh Depth
50	1-1/2	-	-	-	-	-	-
300	2-1/2	210/2D.S.	7-1/2	12	6	40	32
305	3-1/2	210/2D.S.	8-3/4	11	5	38	23
302	5-1/2	210/3D.S.	8-1/4	11	3	40	14

Nets were set at the 15-ft depth contour in late afternoon, left overnight and retrieved the following morning for an average fishing time of 18 hr. Surface and bottom temperatures were taken at each sampling location, prior to the retrieval of nets, using a Whitney TC-5A Thermistor Thermometer. All gill netting was done from the commercial trawler, Chambers Brothers.

Shore-line seining was conducted on 11 April, 21 May, 26 June, 23 July, 27 August, 27 September, 23 October and 14 November. Fish were sampled using a 30-ft long and 6-ft deep minnow seine of 1/4 in Ace mesh with a 6 ft x 6 ft bag of 1/8 in Ace mesh. Seining was conducted after sundown. Two to four hauls were made at each location, with each haul covering approximately 100 ft of shoreline.

Fish eggs and larvae were sampled using the Homelite suction pump described in Chapter 8, Benthos. Pumping was done on 13 April, 22 May, 24 July, 26 September, and 13 and 17 November. The pump was operated for approximately three minutes at each location. The end of the intake hose was drawn along the bottom as the boat drifted with the current or wind.

Zooplankton entrainment samples collected from the KNPP forebay were examined for entrained fish eggs and larvae. A description of the sample collection technique may be found in Chapter 6, Zooplankton Physiology.

All fish collected were identified to species. Fish collected in suitable condition were tagged with anchor tags, measured, and returned to the lake in an attempt to monitor fish movements in the area of the Plant. All other fish collected were weighed and measured and condition determined. The condition of a fish is described in terms of the condition factor (K^{tl}). The condition factor is a description of the relative plumpness or well-being of the fish (Carlander 1950) and is expressed as a relationship between the fish's length and weight, as follows:

$$K^{tl} = \frac{w \times 10^5}{tl^3}$$

where: w is the weight of the fish in grams
tl is the total length of the fish in millimeters

Scales for age and growth analyses were taken from selected salmonids and yellow perch at various times throughout the study period. Representative individuals of sport and commercial species were sexed and gonadal conditions were noted. The following five basic stages were used to describe the gonadal conditions of fish collected:

Stage I: Immature - Young individuals not yet engaged in reproduction, very small sexual organs close under the vertebral column, sex not usually apparent to the naked eye;

Stage II: Mature - Sexual organs well developed with eggs clearly discernable, testes reddish-white;

Stage III: Ripe - Sexual organs filling ventral cavity, testes white, gonads achieved maximum weight, but sexual products do not extrude even with light pressure;

Stage IV: Ripe and running - Eggs or milt extrude with slight pressure, most eggs translucent; and

Stage V: Spent - Testes and ovaries empty, a few eggs in state of reabsorption, gonads have appearance of deflated sacs.

Stomachs were excised from selected specimens, preserved in 10% formalin and returned to the laboratory for content analysis. Stomachs were examined individually and the total volume of each food item recorded. Food items were identified to the lowest possible taxon and percent frequency of occurrence of each category calculated.

Pump and entrainment samples were examined in the laboratory and any eggs collected were identified, counted and the diameter measured and recorded. Larval fish collected by this method were identified and measured for total length.

III. Results and Discussion

A. Water Temperature

Bottom water temperatures at gill net locations ranged from 16.1C at Location B on 25 July to 2.3C at Locations A and B on 14 April (Table 9.1). Water temperatures were highest in July and August. June water temperatures were lower than those recorded in May, September or October; and at Location C in June the temperature was only 1.1C warmer than the average temperature recorded in November. The greatest difference in temperature on a given sampling day occurred on 25 July, when the temperature at Location B was 1.7C warmer than the temperature recorded at Location A.

Water temperatures at minnow seine locations were usually higher than at gill net locations. Temperatures ranged from 17.5C at Location 5 on 27 August to 2.1C at Location 19 on 11 April. Temperatures were highest in July and August.

B. Fish Collections

1. General

A total of 24 fish species were collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973 (Table 9.2), with a total catch of 5427 individuals. Collections made at Locations A/5 (gill net Location A and corresponding minnow seine Location 5) accounted for 2198 fish (40% of the total catch), while collections made at Locations B/9 provided 1615 fish (30%), and collections from Locations C/19 provided 1614 fish (30%).

Gill net collections accounted for 3993 fish (74% of the total catch),

Table 9.1 Bottom water temperature (°C) recorded at fish sampling locations in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

	Temperatures at Gill Net Locations							
Location	April 14	May 23	June 27	July 25	August 29	September 27	October 24	November 14
A	2.3	9.8	7.2	14.4	13.0	10.8	8.2	6.0
B	2.3	9.6	6.9	16.1	13.1	10.9	8.0	6.1
C	2.9	10.2	7.0	15.8	12.9	10.1	7.7	5.6

	Temperatures at Minnow Seine Locations							
Location	April 11	May 21	June 26	July 23	August 27	September 27	October 23	November 14
5	2.4	12.3	7.8	17.4	17.5	12.8	10.4	6.1
9	2.3	12.2	7.4	17.3	17.3	12.8	10.2	6.3
19	2.1	12.3	7.6	16.7	17.4	12.2	10.3	5.2

Table 9.2 Fish species and numbers of each collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Species	Scientific Name[a]	Number of fish by combined location[b]			
		A/5	B/9	C/19	Total
Alewife	*Alosa pseudoharengus*	1175	654	977	2806
Yellow perch	*Perca flavescens*	293	303	113	709
Rainbow smelt	*Osmerus mordax*	172	70	114	356
Lake trout	*Salvelinus namaycush*	109	141	106	356
Lake chub	*Couesius plumbeus*	149	115	72	336
Slimy sculpin	*Cottus cognatus*	80	142	65	287
White sucker	*Castostomus commersoni*	90	126	57	273
Longnose dace	*Rhinichthys cataractae*	80	33	31	144
Longnose sucker	*Catostomus catostomus*	13	12	45	70
Coho salmon	*Oncorhynchus kisutch*	12	9	4	25
Lake whitefish	*Coregonus clupeaformis*	3	2	7	12
Brown trout	*Salmo trutta*	7	1	3	11
Chinook salmon	*Oncorhnychus tshawytscha*	4	0	6	10
Gizzard shad	*Dorosoma cepedianum*	2	0	7	9
Rainbow trout	*Salmo gairdneri*	1	2	5	8
Spottail shiner	*Notropis hudsonius*	3	0	0	3
Fathead minnow	*Pimephales promelas*	1	0	1	2
Black bullhead	*Ictalurus melas*	1	1	0	2
Carp	*Cyprinus carpio*	1	1	0	2
Ninespine stickleback	*Pungitius pungitius*	1	1	0	2
Bloater	*Coregonus hoyi*	0	0	1	1
Round whitefish	*Prosopium cylindraceum*	0	1	0	1
Mottled sculpin	*Cottus bairdi*	1	0	0	1
Shorthead redhorse	*Moxostoma macrolepidotum*	0	1	0	1
Total		2198	1615	1614	5427
Percent		40.5	29.8	29.7	100.0

[a] Scientific names according to Bailey (1970).

[b] Represents gill net and corresponding minnow seine location.

while minnow seine collections yielded 1434 fish (26%) (Table 9.3). Yellow perch, lake trout, longnose sucker, coho salmon, lake whitefish, carp, bloater, round whitefish and shorthead redhorse were taken only by gill nets. Species taken only by minnow seine were slimy sculpin, longnose dace, gizzard shad, spottail shiner, fathead minnow, ninespine stickleback and mottled sculpin. Species collected by both methods were alewife, rainbow smelt, lake chub, white sucker, brown trout, chinook salmon, rainbow trout and black bullhead.

The greatest number of fish taken in gill nets was at Location A and the lowest catch was at Location B; however, catches did not differ greatly between locations.

The largest number of fish collected by minnow seine was at Location 5, which corresponds to gill net Location A. Catches at minnow seine Locations 9 and 19 were relatively lower than catches at corresponding gill net locations. Location 19, corresponding to gill net Location C, produced only 20% of the total minnow seine catch while Location 9, corresponding to gill net Location B, produced 29% of the total minnow seine catch.

2. Discussion of Species

Alewives were the most abundant species collected in 1973 (Table 9.3). A total of 2102 (75%) alewives were taken in gill nets and 704 (25%) were collected by minnow seine. Alewives were taken in low numbers only in April and November (Figure 9.1). The largest catch of adult alewives occurred in May (45%) and substantial catches of adult fish continued through July.

Table 9.3 Fish species collected by gill net and minnow seine in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

	Number of Fish/Location							
	Gill Net Locations				Minnow Seine Locations			
Species	A	B	C	Total	5	9	19	Total
Alewife	751	471	880	2102	424	183	97	704
Yellow perch	293	303	113	709	0	0	0	0
Rainbow smelt	113	27	46	186	59	43	68	170
Lake trout	109	141	106	356	0	0	0	0
Lake chub	84	102	52	238	65	13	20	98
Slimy sculpin	0	0	0	0	80	142	65	287
White sucker	88	125	57	270	2	1	0	3
Longnose dace	0	0	0	0	80	33	31	144
Longnose sucker	13	12	45	70	0	0	0	0
Coho salmon	12	9	4	25	0	0	0	0
Lake whitefish	3	2	7	12	0	0	0	0
Brown trout	6	1	1	8	1	0	2	3
Chinook salmon	3	0	5	8	1	0	1	2
Gizzard shad	0	0	0	0	2	0	7	9
Rainbow trout	0	1	2	3	1	1	3	5
Spottail shiner	0	0	0	0	3	0	0	3
Fathead minnow	0	0	0	0	1	0	1	2
Black bullhead	1	0	0	1	0	1	0	1
Carp	1	1	0	2	0	0	0	0
Ninespine stickleback	0	0	0	0	1	1	0	2
Bloater	0	0	1	1	0	0	0	0
Round whitefish	0	1	0	1	0	0	0	0
Mottled sculpin	0	0	0	0	1	0	0	1
Shorthead redhorse	0	1	0	1	0	0	0	0
Total	1477	1197	1319	3993	721	418	295	1434
Percent	37.0	30.0	33.0	100.0	50.3	29.2	20.5	100.0

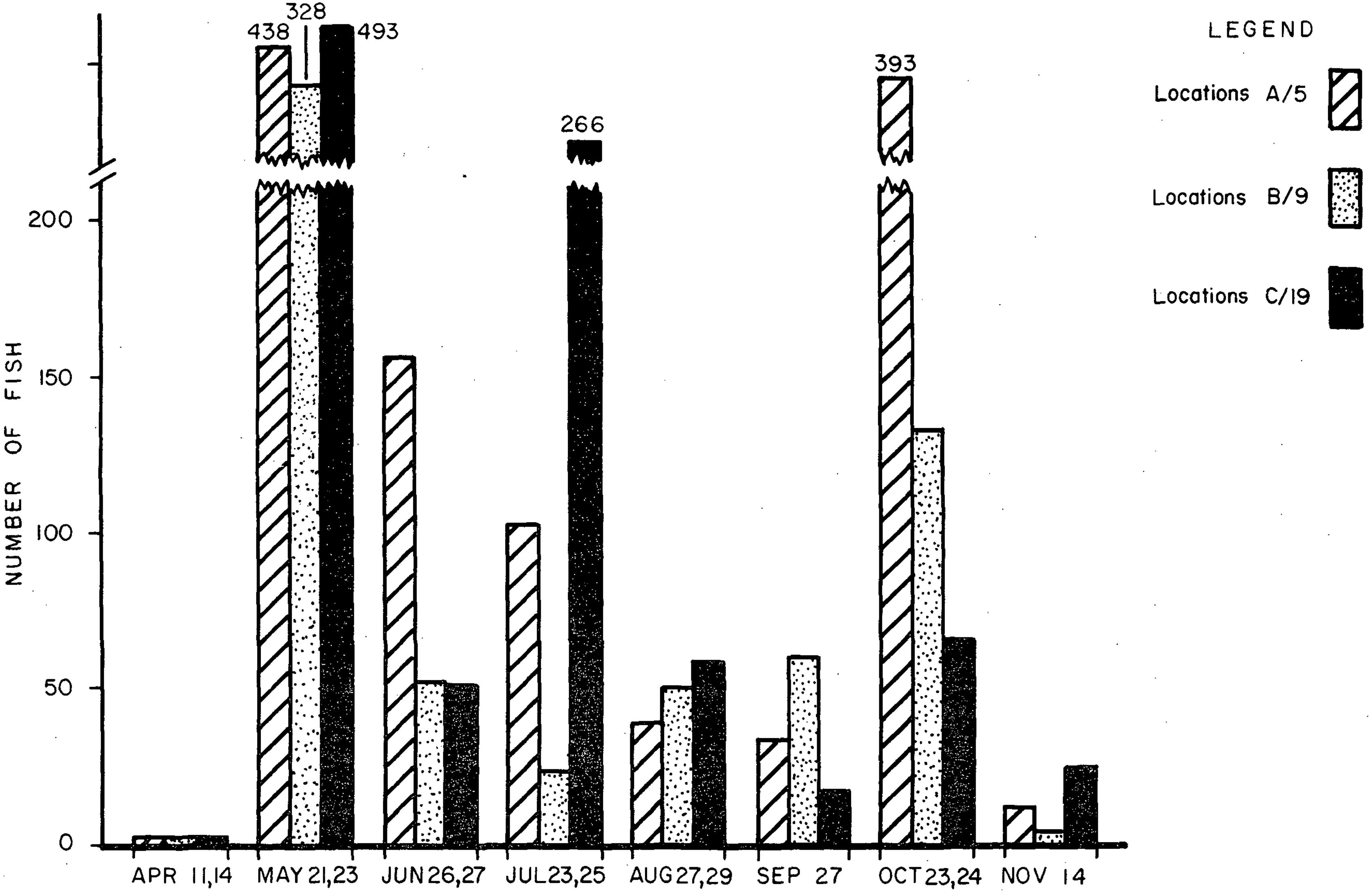

Figure 9.1. Alewife collected by gill net and minnow seine in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973 (where two dates appear, the first date is the date of minnow seining).

Adult fish were common in the area until October after which their numbers dropped off sharply. Adult alewives were collected primarily in gill nets and were most numerous at Location C. Minnow seine collections in May and June consisted primarily of adult and yearling fish. Young-of-the-year alewives were first collected in August, and their numbers increased in September. A large number of young-of-the-year fish was collected at Location 5 in October. In November alewife numbers at minnow seine locations declined sharply. Alewives collected by minnow seine were most numerous at Location 5 (60%) and least abundant at Location 19 (14%). Of the total alewife catch, 42% were collected at Locations A/5, 35% at Locations C/19 and 23% at Locations B/9.

On the basis of alewife size distribution (Table 9.4), it appears that all expected age groups were collected during 1973 (Norden 1967). Several age groups were collected in the minnow seine hauls, but only adult fish, ranging in size from 140 mm to 210 mm, were collected in the gill nets. Adult fish, age groups II to IV, were collected during each sampling period. Adult fish were taken in spawning condition in June and July, and all fish were spent by August. Yearling alewives were collected only from May to July. Young-of-the-year alewives were taken from August to November. Alewife eggs were collected in pump samples in July (Table 9.5). These life history data suggest that successful spawning was occurring within the sampling area during 1973; however, it is impossible to estimate the relative spawning success due to the limitations of the investigation.

Yellow perch were the second most abundant species collected in

Table 9.4 Length frequency distribution of alewife collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Size Group(mm)	Number of Fish/Size Group/Month								Total Number	Average Weight(g)	Average Condition
	April	May	June	July	August	September	October	November			
20-29	0	0	0	0	3	0	2	0	5	-[a]	-
30-39	0	0	0	0	4	16	9	0	29	-	-
40-49	0	0	0	0	0	7	21	1	29	-	-
50-59	0	0	0	0	0	0	20	0	20	-	-
60-69	0	0	2	0	0	0	3	0	5	-	-
70-79	0	4	2	1	0	0	3	0	10	2.2	0.61
80-89	0	0	7	0	0	0	1	0	8	3.7	0.58
90-99	0	2	3	0	0	0	0	0	5	5.1	0.62
100-109	0	0	1	0	0	0	0	0	1	9.0	0.73
110-119	0	1	1	0	0	0	0	0	2	10.0	0.72
120-129	0	1	1	0	0	0	0	0	2	12.0	0.64
130-139	0	2	1	0	0	0	0	0	3	17.7	0.69
140-149	0	2	1	0	0	0	1	0	4	22.8	0.76
150-159	0	15	6	2	3	6	1	1	34	29.5	0.79
160-169	1	33	10	4	13	13	7	1	82	31.5	0.71
170-179	1	32	15	8	11	12	7	15	101	35.6	0.66
180-189	3	25	7	11	8	6	1	8	69	39.7	0.65
190-199	1	15	2	6	2	1	0	2	29	45.7	0.64
200-209	0	5	0	1	0	0	1	0	7	50.7	0.60
210-219	0	0	0	1	0	0	0	0	1	55.0	0.59

[a] Not taken.

Table 9.5 Early life stages of fish collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Date	Species	Life Stage	No.	Average Size(mm)^a	Sampling Location	Sampling Method
April 13	Burbot(<u>Lota lota</u>)	Larva	1	4.3	6	Vertical Plankton Tow
	Burbot	Larva	1	3.8	8	Vertical Plankton Tow
	Burbot	Larva	2	3.5	13	Vertical Plankton Tow
	Burbot	Larva	1	4.3	16	Vertical Plankton Tow
May 22	Rainbow smelt	Egg	16	0.99	12	Pump
	Unidentified Cyprinid	Egg	1	1.30	21	Pump
July 24	Alewife	Egg	58	1.04	6	Pump
	Alewife	Egg	2	1.00	7	Pump
	Alewife	Egg	101	0.96	12	Pump
	Alewife	Egg	280	1.02	20	Pump
	Gizzard shad	Egg	2	0.83	20	Pump
	Alewife	Egg	2	1.12	21	Pump
	Slimy sculpin	Larva	3	11.0	21	Pump
September 26	Slimy sculpin	Juvenile	1	31.0	6	Pump
	Slimy sculpin	Juvenile	1	29.0	11	Pump

1973. They were collected during each sampling period (Figure 9.2). The largest catches of yellow perch were taken in September and August at Locations A and B, 36 and 33%, respectively. Catches at Location C were similar from May through September. Numbers of yellow perch were almost identical at Locations A and B, while only 16% of the total catch was taken at Location C. No yellow perch were taken by minnow seine.

A total of 133 yellow perch were examined for age and growth (Table 9.6). Size groups ranged from 140 mm to 330 mm, representing age groups II through VIII. Age determinations were based on the number of winters each fish had survived past January 1. Age group IV fish were the most numerous of those examined (29%). Age group V fish were the next most abundant (22%) and age groups III and VI were almost equal, 14% and 16%, respectively. Age groups II, VII and VIII comprised 10%, 8% and 2% of the fish examined, respectively. Considerable overlap in lengths and weights was observed between age groups, but average growth data are comparable to those reported by Hile and Jobes (1941).

The majority of yellow perch collected in May were in ripe condition with some males ripe and running. By the June sampling, the majority of fish were spent with some still ripe and running. Gonadal examination of perch in July showed all fish were spent. It appears that yellow perch may have spawned within the study area during the month of June, but no eggs, larvae or young-of-the-year were collected, leaving some question as to their spawning success.

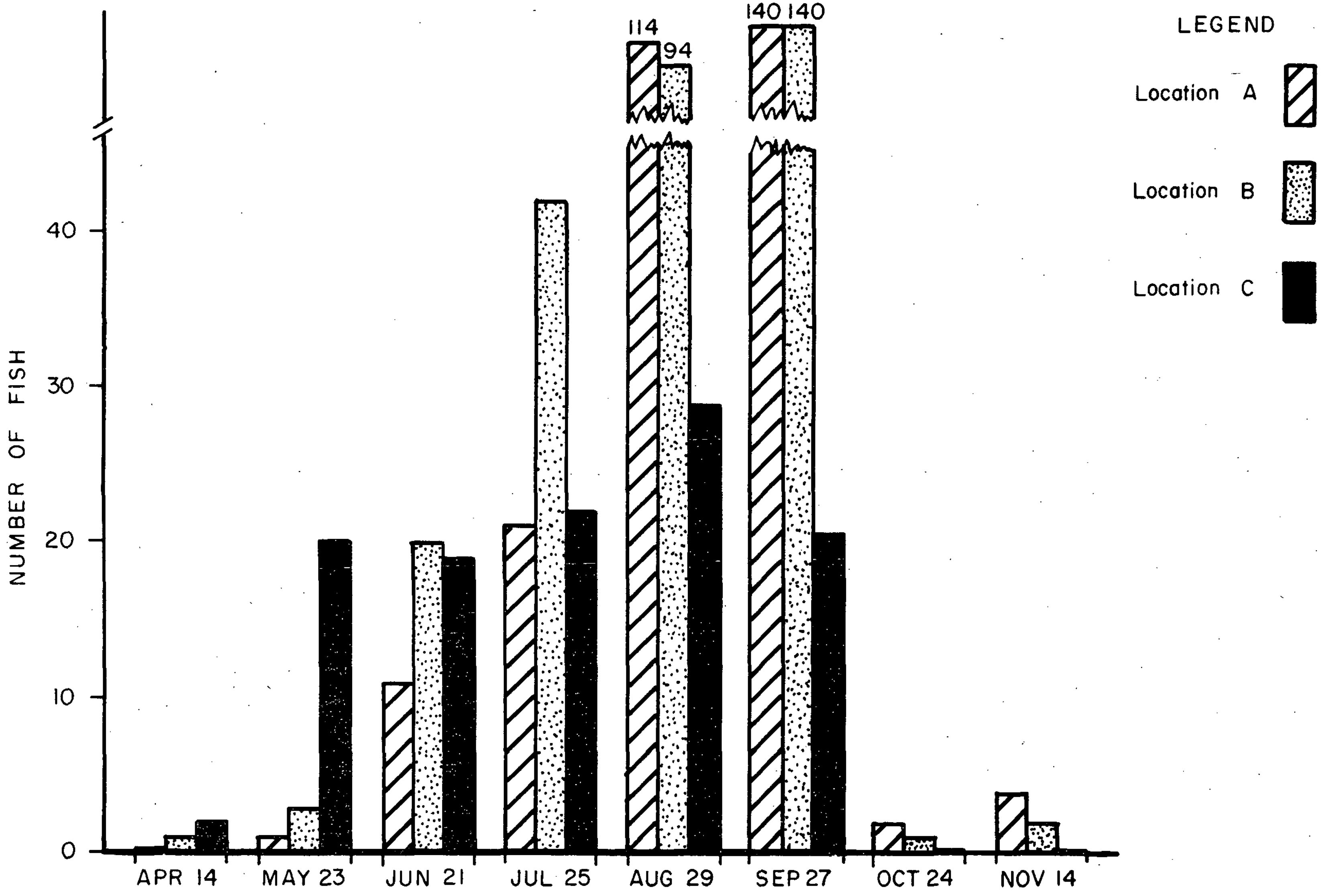

Figure 9.2. Yellow perch collected by gill net in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Table 9.6 Length frequency distribution of yellow perch of different age groups collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Size Class (mm)	Number of Fish/Age Group/Size Class						
	Age Group						
	II	III	IV	V	VI	VII	VIII
140-149	1	0	0	0	0	0	0
150-159	0	0	0	0	0	0	0
160-169	1	0	0	0	0	0	0
170-179	5	1	0	0	0	0	0
180-189	3	0	0	0	0	0	0
190-199	3	0	0	0	0	0	0
200-209	0	1	1	0	0	0	0
210-219	0	3	1	0	0	0	0
220-229	0	8	3	3	0	0	0
230-239	0	3	13	3	0	0	0
240-249	0	4	9	3	1	0	0
250-259	0	0	10	4	0	0	0
260-269	0	0	1	9	3	0	0
270-279	0	0	0	5	3	1	1
280-289	0	0	0	0	2	1	0
290-299	0	0	0	1	2	3	0
300-309	0	0	0	1	6	3	1
310-319	0	0	0	0	2	2	0
320-329	0	0	0	0	2	0	0
330-339	0	0	0	0	0	0	1
Number of Fish	13	19	38	29	21	10	3
Average Total Length(mm)	176.6	221.8	239.1	255.7	289.0	296.1	301.7
Average Weight(g)	66.7	145.8	188.4	230.0	369.3	378.5	421.7
Average Condition(Ktl)	1.16	1.31	1.36	1.34	1.48	1.45	1.49

Yellow perch stomachs contained a variety of food items (Table 9.7). Sculpins and crayfish were the most abundant organisms in their diet.

A total of 356 lake trout were collected in 1973, and all were taken in gill nets (Table 9.3). Of the total catch, 141 (40%) of the lake trout were taken at Location B, while Locations A and C produced 109 (31%) and 106 (30%), respectively.

Lake trout were taken in low numbers in April, August and November, and no lake trout were collected in July (Figure 9.3). Thirty-eight fish (11%) were taken in May, 21 (6%) were taken in June, and 66 (18%) were taken in September. The largest monthly collection of lake trout occurred in October when 207 (58%) were taken. The largest individual catch was taken at Location B on 24 October when 97 (27%) fish were collected in one net. Collections at Locations A and C on the same date accounted for 73 (20%) and 37 (10%) fish, respectively.

Virtually all lake trout in Lake Michigan are planted by state and federal agencies and fin clipped to document age and planting locations. A list of fin clips observed on lake trout collected in 1973 are shown in Table 9.8. The majority of lake trout taken in 1973 were planted locally; however, a wide variety of planting locations were indicated by the fin clips on the remaining individuals. Five fish were collected that did not have fin clips. These fish may have regenerated the clipped fins or, less likely, they may have originated from natural reproduction.

Ages of lake trout ranged from three to nine years (Table 9.9).

Table 9.7 Food items found in stomachs of yellow perch collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Food Item	Number Present	% Frequency Occurrence	Volume (ml)	% Total Volume
Sculpin	84	62.8	90.3	64.7
Alewife	4	4.3	13.2	9.5
Longnose dace	1	1.4	5.0	3.6
Unidentified fish	8	11.4	2.4	1.7
Crayfish	16	21.4	26.6	19.1
Ephemeroptera (Mayfly naiad)	1	1.4	*[a]	*
Unrecognizable	-	-	2.0	1.4

Number of Stomachs Containing Food	70
Number of Empty Stomachs	45

[a] *Trace (less than 0.1 ml in volume).

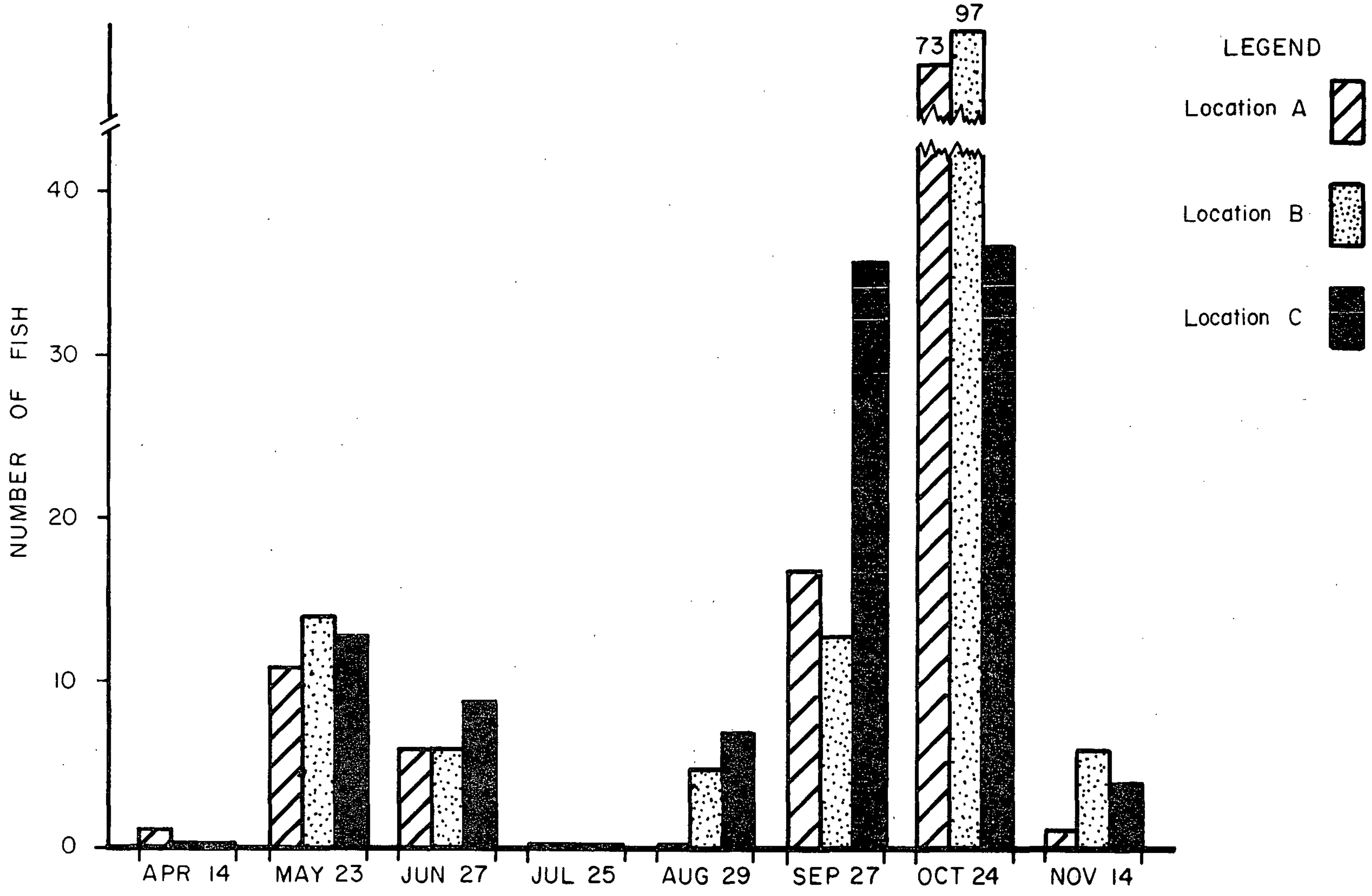

Figure 9.3. Lake trout collected by gill net in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Table 9.8 Fin clips observed on lake trout collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Year Class	Fin Clip	Planting Location	Total Number
1964	Ad	Kewaunee, Door Peninsula	6
	LV	Epoufette, Gulliver, Naubinway	1
	RV	Grand Traverse Bay	1
1965	LP	Kewaunee, Sturgeon Bay, Rowley's Bay	7
	RP	Michigan Waters: 3MM, 4MM, 5MM, 7MM	3
	BV	Milwaukee Reef	1
1966	AdLV	Kewaunee, Sand Bay, Sturgeon Bay	132
	AdRP	Ludington, New Buffalo, Leland Port Sheldon	2
	AdLP	Grand Traverse Bay, Charlevoix, Petoskey	1
1967	LV	Kewaunee, Algoma	110
	D	Ludington to Manistee, Sheboygan to Port Washington	15
	AdBV	Gills Rock	2
	Ad	Great Lakes Naval Dock, Bethlehem Steel Dock, New Buffalo, Port Sheldon	1
	DRP	Ludington, Leland, Frankfort	1
	DLP	Grand Traverse Bay	1
1968	RP	Kewaunee, Manitowoc	28
	DLV	Sturgeon Bay, Green Bay	5
	LP	Michigan Waters: Arcadia, Pentwater, Montague, Port Sheldon, New Buffalo	3
1969	AdRV	Lake Wide	17
1970	LV	Lake Wide	12
No clip			5

Table 9.9 Year class distribution of lake trout collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Age Group	Number of Lake Trout/Month/Location/Year Class																					
	April 14			May 23			June 27			August 29			September 27			October 24			November 14			
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	Total
IX	0	0	0	0	1	0	0	0	0	0	2	0	1	0	1	0	0	0	0	2	1	8
VIII	0	0	0	1	2	0	2	0	0	0	0	0	0	1	3	0	1	0	0	1	0	11
VII	1	0	0	5	3	3	0	0	1	0	1	4	10	10	24	29	29	12	0	2	1	135
VI	0	0	0	1	2	2	0	1	0	0	2	0	3	0	3	41	55	18	0	1	1	130
V	0	0	0	1	2	0	1	1	1	0	0	3	2	1	3	3	12	6	0	0	0	36
IV	0	0	0	2	3	7	1	2	0	0	0	0	0	0	1	0	0	0	0	0	1	17
III	0	0	0	1	1	1	2	2	5	0	0	0	0	0	0	0	0	0	0	0	0	12

Note - No lake trout collected in July.

Age groups VI and VII were most abundant and almost equal in number with 130 and 135 fish in each respective age group. These two age groups comprised 76% of all lake trout taken. Age group V was the third most numerous group containing 36 individuals. The remaining age groups accounted for a total of 48 individuals. Age groups VI and VII were collected during each sampling period, except July when no lake trout were collected. Age group VII fish were most abundant in both September and October. Age group VI fish were taken in large numbers only in October. All age group III fish were collected in May and June. Age group IV fish were taken primarily in May and June, and the highest concentration of age group V fish occurred in October. No pattern of abundance for age groups VIII and IX was determined within the study area. No lake trout younger than age group III were collected.

Size class distribution of lake trout (Table 9.10) was based on rather limited data compiled throughout the study period. In attempting to return to the lake alive, as many fish as possible, insufficient numbers of lake trout were weighed. The largest growth increments were between age groups IV and V. The second greatest average growth occurred between age groups III and IV. Average growth increments appeared to become relatively stable between age groups V through VIII. Data presented on age group IX are from only one individual as all other fish in that age group were tagged and returned to the lake without being weighed.

Sex was easily determined in age group V and older lake trout. Approximately one half of the fish in age group IV had matured sufficiently to

Table 9.10 Average lengths, weights and condition factors of lake trout from each age group collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Age Group	Year Class	Average Total Length(mm)	Average Weight (Kg)	Average Condition (K^{tl})[a]
IX	1964	705.0	3.800	1.08
VIII	1965	725.5	4.725	1.24
VII	1966	711.2	4.045	1.11
VI	1967	677.4	3.398	1.08
V	1968	647.1	3.055	1.11
IV	1969	496.4	1.343	1.08
III	1970	406.9	0.649	0.96
No Clip		618.0	-[b]	-

[a] Condition factors calculated from total length.

[b] Not taken. Fish tagged and returned to lake.

determine their sex. Age group III fish had not matured sufficiently to determine their sex. Equal numbers of males and females were observed in older fish collected from April through August. During September and October males comprised 74% of all lake trout examined.

Lake trout collected in September were in ripe condition. October collections found virtually all lake trout ripe and running. Only three fish were examined for gonadal development in November, all of which were male, one still ripe and running while the other two were spent. It appears that lake trout may have spawned in or near the study area in late October or early November, but no eggs, larvae or young-of-the-year were collected. It is difficult to determine if lake trout could have spawned successfully, as successful natural reproduction of lake trout stocks in Lake Michigan has not yet been reported in recent years (Wells and McLain 1972).

Lamprey marks were found on lake trout in age group IV and older (Table 9.11). No scars or wounds were observed in age group III fish. In those age groups were adequate numbers of fish were examined, the incidence of scarring was higher in age group VII fish and the incidence of wounding was relatively equal between age groups VI and VII. The scarring rate was highest in age group VIII fish, but inadequate numbers of fish were examined to determine if this observation was significant.

Analyses of the stomach contents of lake trout showed alewives and rainbow smelt to be the predominant food items in their diet (Table 9.12).

Table 9.11. Percent of lamprey scars and wounds observed on lake trout collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Age Group	Number of Fish Examined	Number Scarred	Percent Scarring	Number Wounded	Percent Wounding
IX	8	1	12.5	1	12.5
VIII	11	6	54.5	1	9.1
VII	124	56	43.4	12	9.7
VI	118	29	24.6	13	11.0
V	30	3	10.0	2	6.7
IV	15	2	13.3	0	0
III	11	0	0	0	0
Combined	317	97	30.6	29	9.1

Table 9.12. Food items found in stomachs of lake trout collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Food Item	Number Present	% Frequency Occurrence	Volume (ml)	% Total Volume
Alewife	23	58.3	420.0	70.9
Smelt	14	37.5	159.0	26.9
Sculpin	8	8.3	13.0	2.2

Number of Stomachs Containing Food	24
Number of Empty Stomachs	41

A total of 356 rainbow smelt were collected during 1973. Catches were almost equal from gill net and minnow seine collections (Table 9.3). Throughout the study period, smelt were most numerous at Locations A/5 (48%). Locations C/19 accounted for 32% of the total catch, and smelt were least abundant at Locations B/9 (20%). Gill net catches of rainbow smelt were highest at Location A (61%) while Location B and C produced 14% and 25%, respectively. Minnow seine catches were more evenly distributed. Location 5 accounted for 35% of the minnow seine catch, Location 9 produced 25% and Location 19 yielded 40% of the catch.

Rainbow smelt were collected during each sampling period (Figure 9.4). The largest catch of smelt was taken in April (33%) and the lowest catch occurred in October (2%). The largest individual catch was taken at Locations A/5 in April.

Rainbow smelt are too small to be effectively sampled by the gill net meshes used. Data collected by this method may not be a true measure of their abundance within the study area. Sizes of smelt collected ranged from 26 to 270 mm (Table 9.13). Smelt collected in April were ripe and running, and by May all adult fish were spent. Smelt eggs were collected in pump samples taken at Location 12 and 22 May (Table 9.5). Young-of-the-year smelt were first collected in July and later in August, October and November. Indications were that rainbow smelt spawned successfully within the study area during 1973.

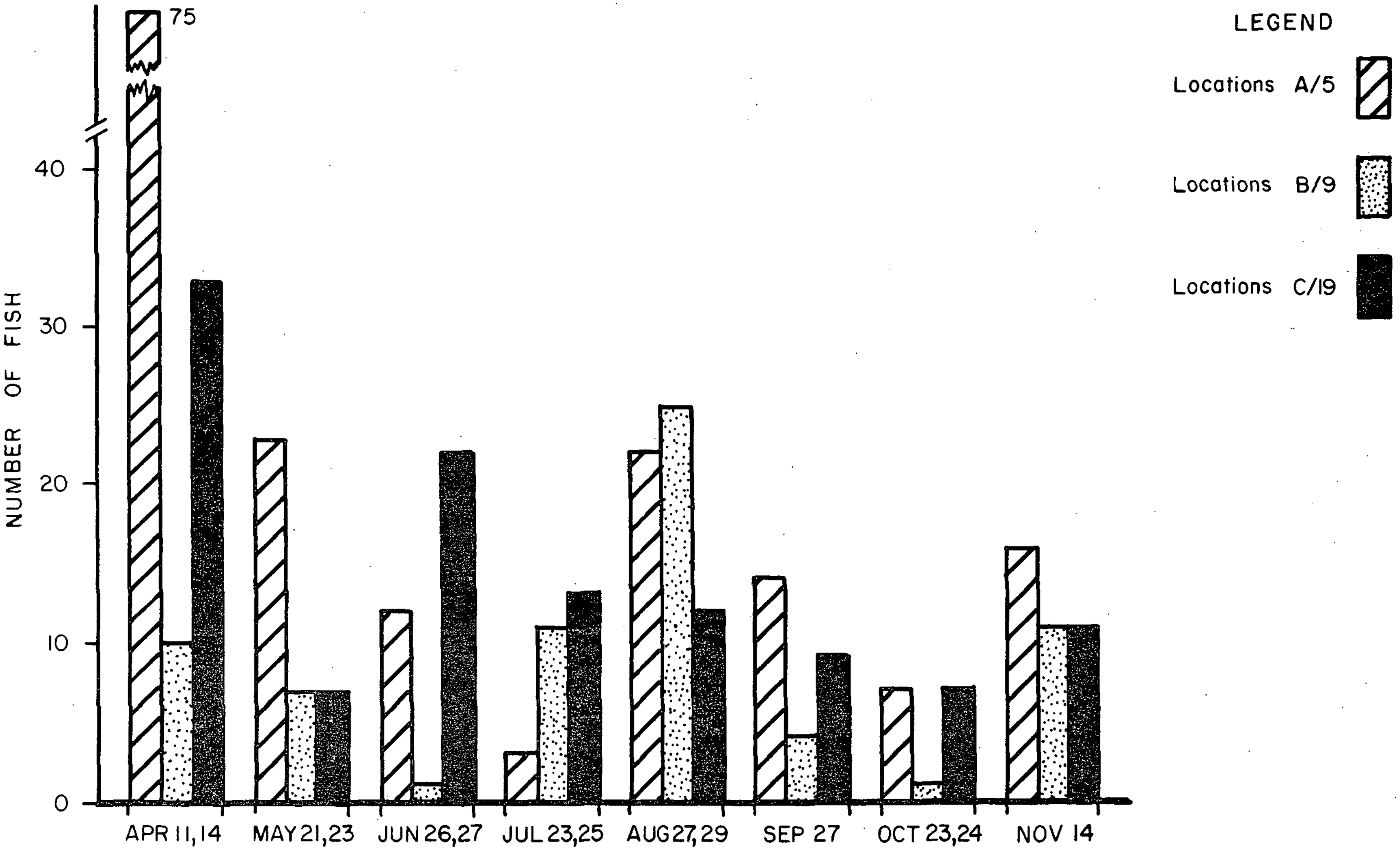

Figure 9.4. Rainbow smelt collected by gill net and minnow seine in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973 (where two dates appear, the first date is the date of minnow seining).

Table 9.13 Length frequency distribution of rainbow smelt collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Size Group(mm)	Number of Fish/Size Group/Month								Total Number	Average Weight(g)	Average Condition
	April	May	June	July	August	September	October	November			
20-29	0	0	0	10	0	0	0	0	10	-[a]	-
30-39	0	0	0	1	39	0	0	0	40	-	-
40-49	0	1	0	0	11	0	5	6	23	-	-
50-59	0	1	3	2	1	0	2	3	12	-	-
60-69	0	6	9	2	0	0	0	0	17	1.3	0.47
70-79	0	5	13	5	1	0	0	0	24	2.1	0.51
80-89	0	5	5	4	3	0	3	0	20	3.2	0.53
90-99	0	2	1	0	1	0	0	0	4	4.8	0.58
100-109	0	4	0	0	0	0	0	0	4	6.8	0.61
110-119	0	0	1	1	1	0	0	1	4	7.5	0.48
120-129	0	1	0	0	0	1	0	0	2	10.5	0.56
130-139	1	2	0	1	0	2	0	0	6	13.2	0.54
140-149	1	2	0	0	0	5	0	0	8	15.4	0.53
150-159	3	3	0	1	1	8	2	3	21	20.3	0.57
160-169	1	1	0	0	1	2	0	1	6	25.8	0.58
170-179	3	0	0	0	0	0	2	3	8	35.0	0.66
180-189	6	1	0	0	0	3	1	4	15	40.9	0.62
190-199	8	0	1	0	0	1	0	6	16	49.0	0.69
200-209	6	0	1	0	0	1	0	3	11	57.3	0.68
210-219	3	0	0	0	0	1	0	6	10	60.0	0.63
220-229	1	0	0	0	0	0	0	1	2	70.0	0.65
230-239	1	1	0	0	0	0	0	2	4	74.0	0.59
240-249	0	1	0	0	0	0	0	0	1	75.0	0.52
250-259	1	1	1	0	0	0	0	0	3	85.0	0.52
260-269	0	0	0	0	0	0	0	0	0	-	-
270-279	1	0	0	0	0	0	0	0	1	115.0	0.58

[a] Not taken.

A total of 336 lake chubs were collected during the study period. This species was collected during all sampling periods (Figure 9.5) and was taken by both gill net and minnow seine. Two hundred thirty-eight lake chubs (71%) were taken by gill nets while 98 (29%) were taken in minnow seine hauls. Of the total catch, 44% were taken at Locations A/5, 34% at Locations B/9 and 21% at Locations C/19. Gill net catches of lake chubs were highest at Location B (43%), followed by Locations A (35%) and Location C (22%). Minnow seine catches of lake chubs were highest at Location 5 (66%) with 20% taken at Location 19 and 13% taken at Location 9. Lake chubs were taken in low numbers only in October (Figure 9.5). The highest individual catch was taken at Locations A/5 in July.

Sizes of lake chubs ranged from 35 to 195 mm (Table 9.14). Adult fish collected in April were ripe and running, and by May all adult fish were spent. No eggs or larvae were collected during the year, but young-of-the year were collected in July, August and September, indicating that lake chubs had spawned successfully within the study area during 1973.

A large number of lake chubs collected during 1973 were infected with black spot (Neascus spp.).

Two hundred seventy-three white suckers were collected during 1973, and all but three were taken in the gill nets (Table 9.3). Forty-six percent of the total gill net catch was taken at Location B, while 33% was taken at Location A and 21% taken at Location C. Only two fish at Location 5 and one fish at Location 9 were captured by minnow seining. No white suckers were

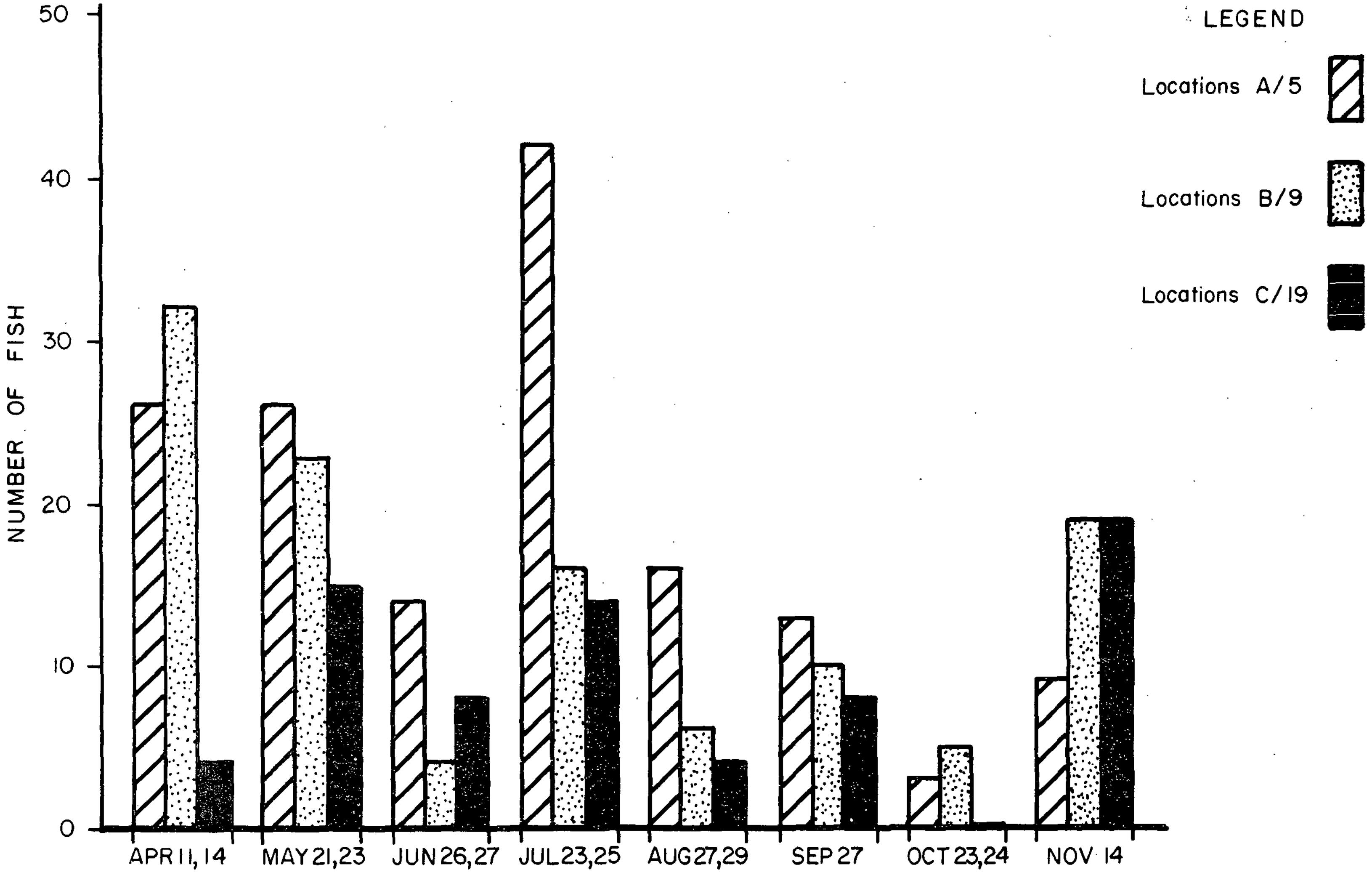

Figure 9.5. Lake chub collected by gill net and minnow seine in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973 (where two dates appear, the first date is the date for minnow seining).

Table 9.14. Length frequency distribution of lake chub collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Size Group(mm)	Number of Fish/Size Group/Month								Total Number	Average Weight(g)	Average Condition
	April	May	June	July	August	September	October	November			
30-39	0	0	0	1	2	2	0	0	5	-[a]	-
40-49	0	0	0	0	4	0	0	0	4	-	-
50-59	0	0	1	0	0	1	0	0	2	-	-
60-69	0	1	0	2	0	0	0	0	3	2.7	0.88
70-79	0	0	1	2	0	0	0	0	3	4.2	0.93
80-89	0	0	0	1	0	0	0	0	1	5.0	0.97
90-99	0	0	0	1	1	1	0	0	3	9.0	1.01
100-109	0	3	0	1	0	0	0	0	4	13.5	1.01
110-119	0	5	5	2	1	0	0	0	13	15.2	0.98
120-129	0	7	1	1	3	0	0	0	12	19.5	1.01
130-139	0	5	4	5	1	0	1	0	16	24.6	1.02
140-149	0	6	2	5	1	0	0	0	14	31.6	1.05
150-159	4	6	2	5	3	4	1	6	31	39.3	1.06
160-169	5	15	0	3	8	9	5	18	63	43.6	1.04
170-179	12	8	7	8	2	11	1	14	63	55.4	1.01
180-189	2	5	2	15	0	3	0	7	34	59.4	0.99
190-199	0	1	0	2	0	0	0	2	5	66.2	0.94

[a] Not taken.

taken in April. White suckers were collected in low numbers in May, June, July and November (Figure 9.6). Large catches were made in August, September and October. The largest individual catch of 75 fish was taken at Location B on 27 September.

Sizes of white suckers ranged from 63 to 510 mm, but the majority of fish fell between two size ranges (Table 9.15). The largest number of fish fell between 330 and 420 mm while a smaller number fell between 250 and 310 mm. Measurements of only seven individuals fell outside these ranges.

No eggs or larvae were collected in the pump samples, and only one young-of-the-year specimen was collected. It appears unlikely that white suckers utilize the study area as a spawning location, as few fish were collected during the spawning season (April and May).

A total of 144 longnose dace were taken during the year, and all were collected by minnow seine (Table 9.3). Longnose dace were most abundant at Location 5 (56%) and almost equally distributed between Locations 9 and 19, 23 and 21%, respectively. Distribution patterns of longnose dace were quite inconsistent. Dace were taken in low numbers in April, June and October (Figure 9.7). In these months, the majority were collected at Location 19, the least productive of the three minnow seine locations. Larger collections of longnose dace were made in May, July, August and September, but the only locations where their numbers remained relatively constant was at Location 5.

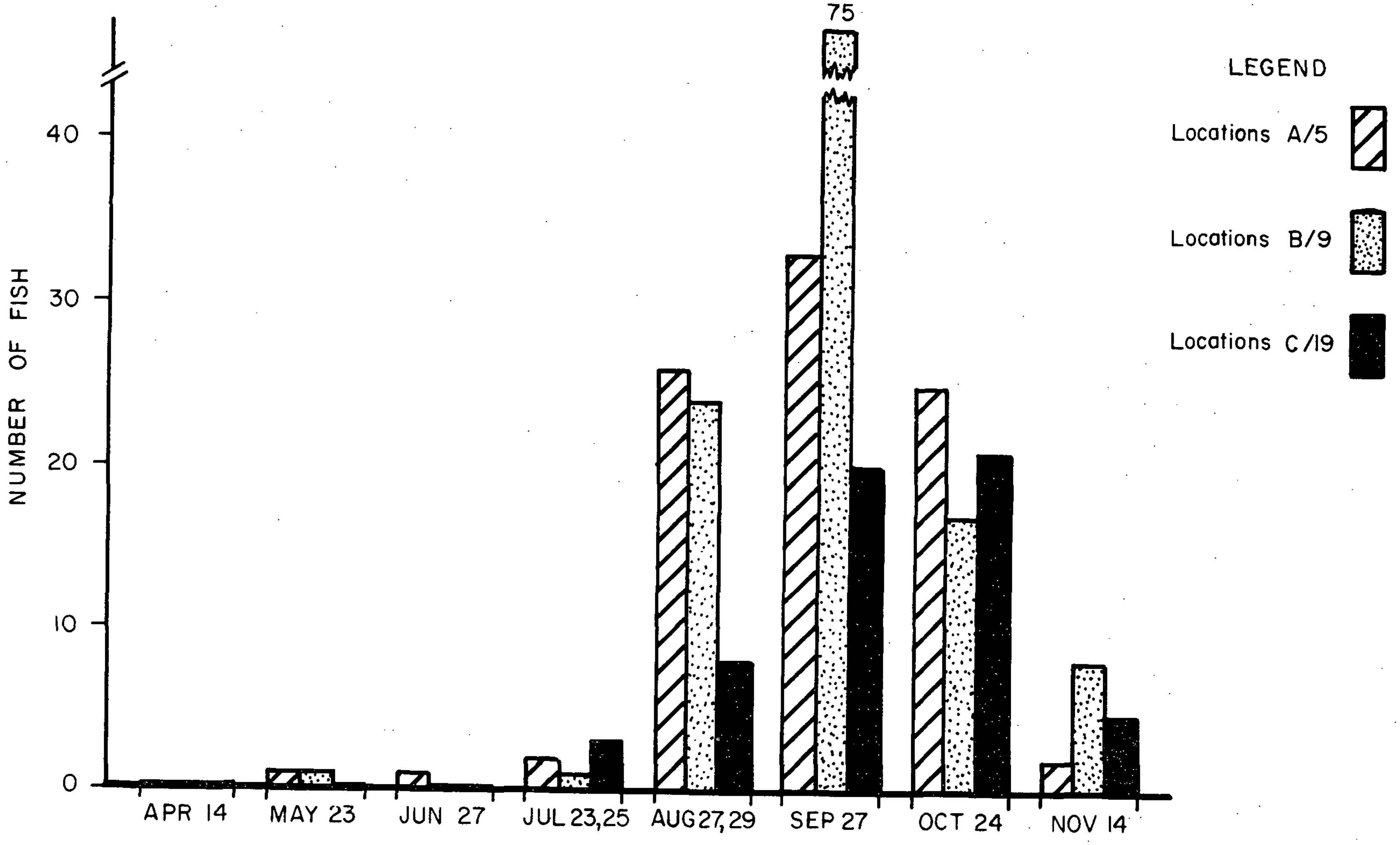

Figure 9.6. White sucker collected by gill net and minnow seine in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973 (where two dates appear, the first date is the date of minnow seining).

Table 9.15 Length frequency distribution of white sucker collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Size Group(mm)	Number of Fish/Size Group/Month								Total Number	Average Weight(g)	Average Condition
	April	May	June	July	August	September	October	November			
60-69	0	0	0	1	0	0	0	0	1	3.0	1.04
70-79	0	0	0	0	0	0	0	0	0	-[a]	-
80-89	0	0	0	0	0	0	0	0	0	-	-
90-99	0	0	0	0	0	0	0	0	0	-	-
100-109	0	0	0	0	0	0	0	0	0	-	-
110-119	0	0	0	0	0	0	0	0	0	-	-
120-129	0	0	0	0	0	0	0	0	0	-	-
130-139	0	0	0	0	0	0	0	0	0	-	-
140-149	0	0	0	0	0	0	0	0	0	-	-
150-159	0	0	0	0	0	0	0	0	0	-	-
160-169	0	0	0	0	1	0	0	0	1	57.0	1.20
170-179	0	0	0	0	1	0	0	0	1	50.0	1.01
180-189	0	0	0	0	0	0	0	0	0	-	-
190-199	0	0	0	0	0	0	0	0	0	-	-
200-209	0	0	0	0	0	0	0	0	0	-	-
210-219	0	0	0	0	0	0	0	0	0	-	-
220-229	0	0	0	0	0	0	0	0	0	-	-
230-239	0	0	0	0	1	0	0	0	1	142.0	1.13
240-249	0	0	0	0	0	0	0	0	0	-	-
250-259	0	0	0	0	3	3	0	0	6	197.5	1.22
260-269	0	0	0	1	5	8	0	0	14	213.6	1.16
270-279	0	0	0	1	10	14	2	0	27	234.1	1.15
280-289	0	0	0	0	3	9	5	0	17	257.9	1.14
290-299	0	0	0	0	2	4	3	0	9	282.2	1.12
300-309	0	0	0	0	0	4	3	0	7	306.4	1.10
310-319	0	0	0	0	0	2	0	0	2	382.5	1.25
320-329	0	0	0	0	0	0	0	0	0	-	-
330-339	0	0	0	0	1	2	0	0	3	483.3	1.26
340-349	0	0	0	0	0	1	1	1	3	515.0	1.27
350-359	0	1	0	0	1	9	2	2	15	571.7	1.29
360-369	0	1	0	0	1	10	6	3	21	596.9	1.24
370-379	0	0	0	1	1	8	15	4	29	638.9	1.23
380-389	0	0	0	0	2	4	8	2	16	676.3	1.20
390-399	0	0	0	1	0	4	6	0	11	719.1	1.19
400-409	0	0	0	0	0	3	7	1	11	805.9	1.23
410-419	0	0	0	0	0	2	3	0	5	878.0	1.26
420-429	0	0	0	1	0	0	1	1	3	993.0	1.32
430-439	0	0	0	0	0	0	1	0	1	1020.0	1.23
440-449	0	0	0	0	0	0	0	0	0	-	-
450-459	0	0	0	0	1	0	0	0	1	1150.0	1.26
460-469	0	0	0	0	0	0	0	0	0	-	-
470-479	0	0	0	0	0	0	0	0	0	-	-
480-489	0	0	0	0	0	0	0	0	0	-	-
490-499	0	0	0	0	0	0	0	0	0	-	-
500-509	0	0	0	0	0	0	0	0	0	-	-
510-519	0	0	0	0	0	0	0	1	1	1800.0	1.35

[a] Not applicable.

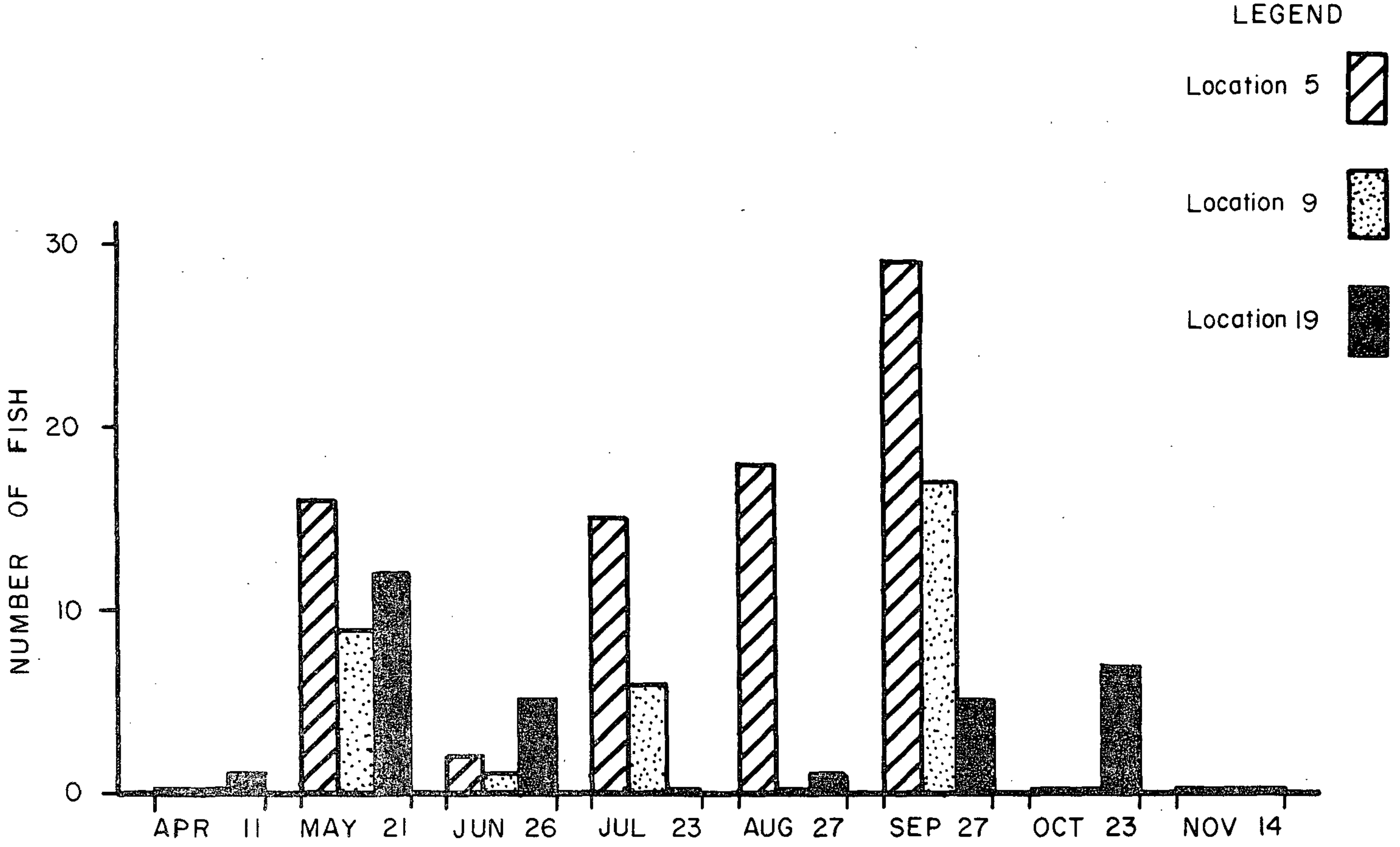

Figure 9.7. Longnose dace collected by minnow seine in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Sizes of longnose dace ranged from 26 to 118 mm (Table 9.16). One female, collected at Location C on 21 May, was ripe and running. No eggs or larvae were collected during the year, but young-of-the-year were collected in September and October. Successful spawning may have taken place within the study area.

Seventy longnose suckers were collected during this study, and all were taken in gill nets (Table 9.3). This species was most numerous at Location C where 64% of the total catch was collected. Numbers collected at Locations A and B were almost equal, producing 13 and 12 specimens, respectively. The largest individual catch was 16 fish taken at Location C on 27 June (Figure 9.8). Longnose suckers were most abundant from June through September, but all monthly catches were considered low.

Sizes of longnose suckers ranged from 270 to 500 mm (Table 9.17). Few fish were collected in spawning condition. Two females were examined on 21 May, one was still ripe while the other was spent. No eggs or larvae were collected, and no young-of-the-year were collected in minnow seine hauls. It does not appear that longnose suckers utilize the study area as a spawning location.

A total of 287 slimy sculpins were collected during the year and all were taken by minnow seine (Table 9.3). Location 9 accounted for 49% of the catch, Location 5 produced 28% and Location 19 produced 23% (Table 9.3). However, these data are misleading since all but five individuals were taken on 21 May. On this date, 140 were collected at Location 9, 78 at Location 5

Table 9.16 Length frequency distribution of longnose dace collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Size Group(mm)	Number of Fish/Size group/Month								Total Number	Average Weight(g)	Average Condition
	April	May	June	July	August	September	October	November			
20-29	0	0	0	0	0	1	1	0	2	-[a]	-
30-39	0	0	0	0	0	0	3	0	3	-	-
40-49	0	0	0	0	0	0	1	0	1	-	-
50-59	0	2	0	0	0	0	1	0	3	-	-
60-69	0	2	1	2	0	0	0	0	5	3.0	1.01
70-79	1	11	2	2	2	9	1	0	28	4.7	1.06
80-89	0	12	3	5	6	13	0	0	39	6.7	1.06
90-99	0	4	1	7	4	14	0	0	30	9.6	1.14
100-109	0	3	0	5	6	8	0	0	22	12.0	1.07
110-119	0	3	0	0	1	6	0	0	10	16.4	1.10

[a] Not taken.

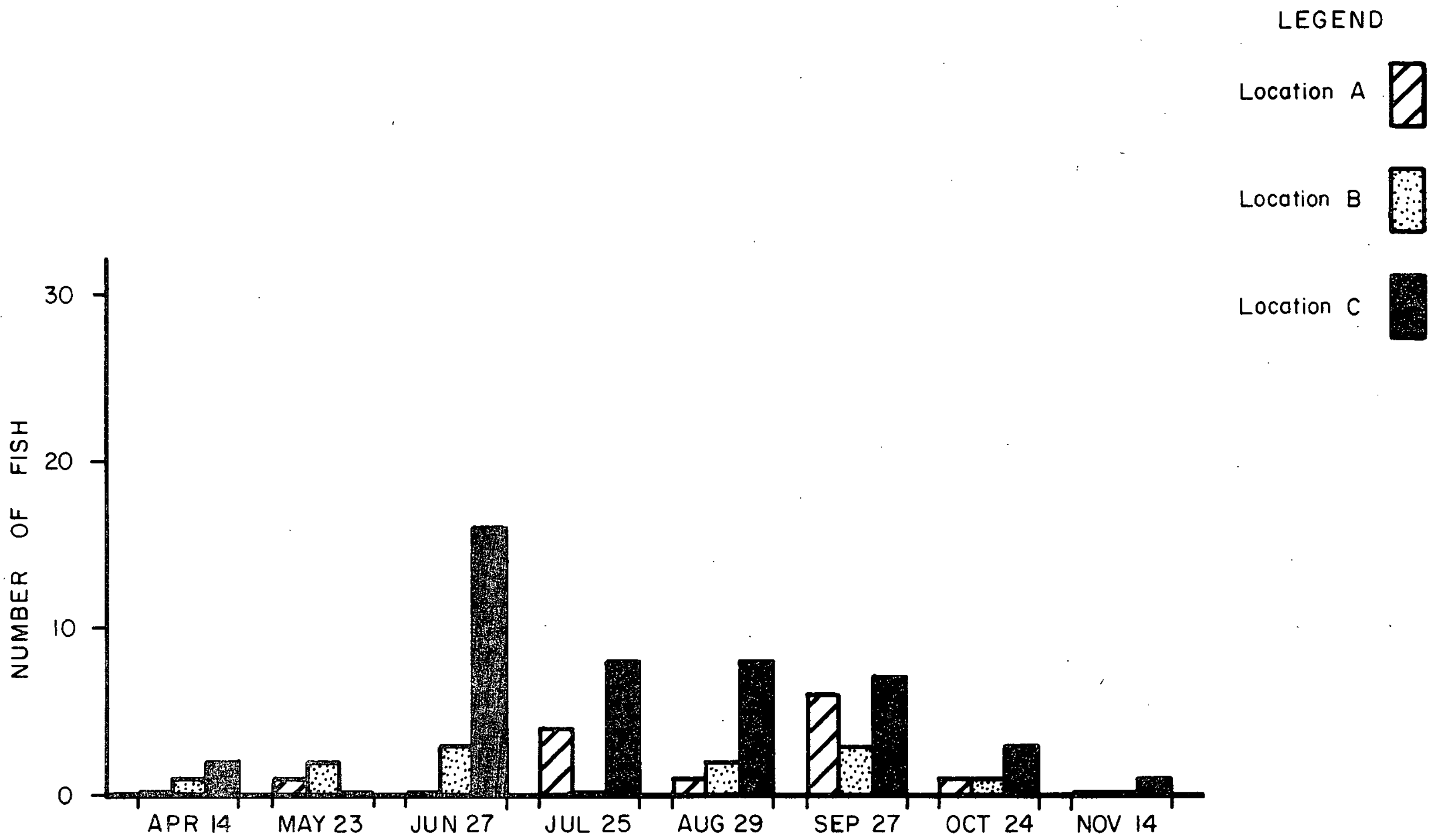

Figure 9.8. Longnose sucker collected by gill net in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Table 9.17 Length frequency distribution of longnose sucker collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Size Group(mm)	Number of Fish/Size Group/ Month								Total Number	Average Weight(g)	Average Condition
	April	May	June	July	August	September	October	November			
270-279	1	0	0	0	0	1	0	0	2	227.5	1.18
280-289	0	0	0	0	0	3	0	0	3	245.0	1.09
290-299	0	0	0	0	0	2	0	0	2	257.5	1.02
300-309	0	0	0	0	0	1	1	0	2	265.0	0.93
310-319	0	0	0	0	0	0	0	0	0	-[a]	-
320-329	0	1	0	0	0	0	0	0	1	385.0	1.11
330-339	0	0	0	0	0	0	0	0	0	-	-
340-349	0	0	0	0	0	0	0	0	0	-	-
350-359	0	0	0	0	0	0	0	0	0	-	-
360-369	0	0	0	0	0	0	0	0	0	-	-
370-379	0	0	1	0	0	0	0	0	1	620.0	1.17
380-389	0	0	2	0	0	2	0	0	4	677.5	1.20
390-399	0	0	2	2	1	3	0	0	8	678.1	1.11
400-409	1	0	1	1	0	1	1	0	5	677.0	1.05
410-419	0	0	3	1	0	1	2	0	7	752.8	1.06
420-429	1	1	5	0	0	0	0	0	7	745.7	0.99
430-439	00	0	1	0	0	0	0	0	1	850.0	1.06
440-449	0	0	3	1	0	0	0	0	4	877.5	1.01
450-459	0	0	1	0	0	0	1	0	2	965.0	1.03
460-469	0	0	0	0	0	0	0	1	1	1140.0	1.17
470-479	0	1	0	0	0	0	0	0	1	1370.0	1.25
480-489	0	0	0	0	0	0	0	0	0	-	-
490-499	0	0	0	0	0	0	0	0	0	-	-
500-509	0	0	1	0	0	0	0	0	1	1370.0	1.09

[a] Not applicable.

and 64 at Location 19. The majority of those examined were adult fish that had already spawned. No eggs were collected in pump samples, but young-of-the-year were collected with the pump in July (Table 9.5). It is reasonable to suspect that slimy sculpins do spawn successfully within the study area.

Twenty-five coho salmon were taken in gill nets during the 1973 study (Table 9.3). Coho were most numerous at Location A (12 fish), while nine were taken at Location B, and only four were collected at Location C. One coho was collected in June, the remainder were collected in July and August. Sizes of coho ranged from 195 to 460 mm. Alewives and smelt were the predominant food items found in their stomachs (Table 9.18).

Twelve lake whitefish were collected in the gill nets in 1973 (Table 9.3). Seven were taken at Location C, three at Location A, and two at Location B. Ten were taken in October while only one was collected in each of September and November. All lake whitefish appeared immature. Sizes ranged from 265 to 420 mm.

Eleven brown trout were collected, eight by gill net and three by minnow seine (Table 9.3). Seven were taken at Locations A/5, three at Locations C/19, and one at Locations B/9. Brown trout were taken in May, July, August, October and November. Sizes of brown trout ranged from 104 to 545 mm. One ripe male was taken in August, but no spawning fish were collected. Yearlings were collected in September, but most brown trout are planted in the lake without marking, making it impossible to determine if these fish were planted or reproduced naturally. Stomach analyses conducted on

Table 9.18 Food items found in the stomachs of various game species collected in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

Species	Stomachs Examined		Food Item	Number	% Freq. Occur.	Vol. (ml)	% Total Volume
	With Food	Empty					
Brown trout	4	2	Alewife	7	75.0	31.0	96.9
			Unidentified fish remains	1	25.0	1.0	3.1
Coho salmon	14	3	Alewife	21	71.4	78.0	91.8
			Smelt	4	14.3	5.0	5.9
			Unrecognizable	-[a]	-	2.0	2.3
Chinook salmon	2	1	Alewife	4	100.0	10.0	100.0

[a] Not applicable.

brown trout showed alewife to be the predominant food item (Table 9.18).

Ten chinook salmon were collected by gill net and minnow seine (Table 9.3). Six were collected at Locations C/19 and four were taken at Locations A/5. Chinook were collected only in May, July and August. Sizes ranged from 74 to 815 mm. Two recently planted chinook salmon were taken by minnow seine in May. No chinook were collected in spawning condition. The only food items found in the stomachs of chinook salmon were alewives (Table 9.18).

Nine gizzard shad were collected in the minnow seine hauls in October and November (Table 9.3). Seven were taken at Location 19 and two were taken at Location 5. All individuals were immature.

Eight rainbow trout were collected by gill net and minnow seine (Table 9.3). Five were taken at Locations C/19, two at Locations B/9 and one at Locations A/5. Rainbow trout were collected in September, October, and November. Sizes ranged from 181 to 660 mm. Fish in spawning condition were taken in October and November.

Incidental species collected and their numbers were: spottail shiner (3), fathead minnow (2), black bullhead (2), carp (2), ninespine stickleback (2), bloater (1), round whitefish (1), mottled sculpin (1) and shorthead redhorse (1) (Table 9.3). In addition to these species, five burbot larvae were collected in plankton net tows on 13 April (Table 9.5).

C. Entrainment

No fish eggs or larvae were found in the entrainment samples collected in the forebay of the Plant. This should not be inferred to indicate that when the pumps are operating continuously entrainment of fish eggs and larvae will not occur.

D. Tagging

A total of 452 fish were tagged and returned to Lake Michigan during 1973. Six species of fish were tagged, but lake trout and yellow perch comprised 51% and 37% of the total, respectively, of fish tagged (Table 9.19). Extremely limited capture/recapture data were obtained as only three fish were recaptured. One lake trout, tagged on 23 May at Location C, was recaptured at a distance of approximately 7.5 miles by a sport fisherman offshore of the Kewaunee harbor on 11 October. One yellow perch, tagged on 23 May at Location C, was recaptured at a distance of 1.9 miles at Location B on 25 July. A second yellow perch tagged on 25 July at Location A, was recaptured at a distance of approximately 40 miles by a commercial fisherman near Sheboygan on 8 October.

The only inference that can be made from these limited data is that there appears to be considerable long-range movement of some fish in and out of the study area. Tagging studies conducted on lake trout in Lake Superior have demonstrated extensive movement of this species (Eschmeyer et al. 1952; Rahrer 1968). Over a period of time, yellow perch will also travel long distances (Mraz 1952). Tagging studies conducted at the Point Beach Nuclear Plant (Spigarelli 1973) indicated considerable movement of tagged species, although only a few marked lake trout were recaptured.

Table 9.19 Summary of fish species tagged and released in Lake Michigan near the Kewaunee Nuclear Power Plant during 1973.

	Number of Fish Tagged/Month/Location																								
	April 14			May 23			June 27			July 25			August 29			September 27			October 23-24			November 14			
Species	A/5	B/9	C/19	A/5	B/9	C/19	A/5	B/9	C/19	A/5	B/9	C/19	A/5	B/9	C/19	A/5	B/9	C/19	A/5	B/9	C/19	A/5	B/9	C/19	Total
Lake trout	1	0	0	5	7	4	5	4	4	0	0	0	0	3	3	9	10	25	64	56	22	1	5	4	232
Rainbow trout	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	2	5
Brown trout	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	3
Yellow perch	0	1	1	1	1	17	7	11	12	13	21	13	24	14	3	14	11	0	0	0	0	4	2	0	170
White sucker	0	0	0	0	0	0	1	0	0	0	0	0	13	6	5	0	0	0	0	0	0	0	0	0	25
Longnose sucker	0	0	0	0	0	0	0	0	0	4	0	2	1	2	7	0	1	0	0	0	0	0	0	0	17
Total	1	1	1	6	8	21	13	15	16	17	21	15	38	25	18	23	22	25	64	58	24	6	8	6	452

E. Comparison of 1971, 1972 and 1973 Catch Data

A qualitative comparison of 1973 data with 1971 and 1972 data (Industrial BIO-TEST Laboratories, Inc. 1972 and 1973) is the only treatment that can be given due to the differences in sampling between years. Sampling locations in 1973 were identical to those in 1972, but only two locations were sampled in 1971,with the gill net and seining Location North of Site and Location At Site corresponding to the 1973 Locations A/5 and B/9, respectively. A comparison of 1972 and 1973 data with 1971 data is based only on catches at comparable sampling locations. The minnow seine employed in 1973 was different than the seine used in 1971 and 1972, and the 50-ft panel of 1 1/2 inch mesh net was added to the gill nets used in 1973. Sampling was conducted once per month in 1973 (8 times), while sampling in 1972 was conducted quarterly, but twice within a 48 hr period each quarter (8 times). In 1971, sampling was conducted twice each in April and October and once each in May, June and July (7 times). Despite these variations, sampling effort was relatively equal for each of the three years.

Twenty-six different species of fish were collected from all sampling locations over the three year period (Table 9.20), but species collected were not the same each year. Chinook salmon and carp were collected only in 1972 and 1973, while brook trout were collected only in 1971. The common shiner was taken only in 1972, while gizzard shad, black bullhead, ninespine stickleback, mottled sculpin and shorthead redhorse were collected only in 1973. Spottail shiner and fathead minnow were not taken in 1972, but were collected in 1971 and 1973.

Table 9.20 Comparison of catch totals for fish species collected in Lake Michigan near the Kewaunee Nuclear Power Plant from 1971 through 1973.

	1973				1972				1971		
	Locations[a]				Locations				Locations[b]		
Species	A/5	B/9	C/19	Total	A/5	B/9	C/19	Total	North	Site	Total
Alewife	534	259	228	1021	31	55	105	191	1172	942	2114
Yellow perch	287	296	108	691	64	159	65	288	30	21	51
Rainbow smelt	86	55	77	218	26	33	70	129	116	51	167
Lake trout	104	134	104	342	79	117	79	275	140	214	354
Lake chub	65	13	20	98	28	1	30	59	8	50	58
Slimy sculpin	80	142	65	287	2	0	1	3	22	5	27
White sucker	89	125	57	271	29	77	14	120	11	28	39
Longnose dace	80	33	31	144	44	6	27	77	31	0	31
Longnose sucker	13	12	45	70	9	62	33	104	5	12	17
Coho salmon	12	8	3	23	3	4	4	11	1	0	1
Lake whitefish	3	2	7	12	0	1	0	1	0	2	2
Brown trout	7	1	3	11	5	8	5	18	8	5	13
Chinook salmon	2	0	6	8	1	1	1	3	0	0	0
Gizzard shad	2	0	7	9	0	0	0	0	0	0	0
Rainbow trout	1	2	4	7	3	6	1	10	0	2	2
Spottail shiner	3	0	0	3	0	0	0	0	0	1	1
Fathead minnow	1	0	1	2	0	0	0	0	7	1	8
Black bullhead	1	1	0	2	0	0	0	0	0	0	0
Carp	1	1	0	2	0	0	1	1	0	0	0
Ninespine stickleback	1	1	0	2	0	0	0	0	0	0	0
Bloater	0	0	1	1	1	0	0	1	0	2	2
Round whitefish	0	1	0	1	4	6	1	11	8	0	8
Mottled sculpin	1	0	0	1	0	0	0	0	0	0	0
Shorthead redhorse	0	1	0	1	0	0	0	0	0	0	0
Brook trout	0	0	0	0	0	0	0	0	5	0	5
Common shiner	0	0	0	0	0	0	1	1	0	0	0
Totals	1373	1087	767	3227	329	536	435	1303	1564	1334	2898
% of Years' Catch	42.6	33.7	23.7	100.0	25.3	41.2	33.5	100.0	54.0	46.0	100.0

[a] Data from 1973 does not include fish collected in 1 1/2 inch mesh gill nets.

[b] Locations North and Site in 1971 correspond to locations A/5 and B/9. Location C/19 had no comparable Location in 1971.

The total catch in 1971 was more than three times greater than in 1972, and was 15% higher than in 1973. The total catch in 1973 was almost three times greater than the total catch in 1972. In 1971, 54% of the total catch was taken at the North of Site sampling locations (equivalent to Locations A/5) and 46% was taken at the At Site Locations (equivalent to Locations B/9). Catch percentages at comparable locations in 1973 were similar with 56% taken at Locations A/5 and 44% at Locations B/9. In 1972, catch percentages showed a reverse trend, with 38% of the catch taken at Locations A/5 and 62% taken at Locations B/9. Comparisons of catch totals from all three sampling locations in 1972 and 1973 failed to show any trends between locations. In 1972, the highest fish catch percentage was at Locations B/9, and the lowest fish catch percentage occurred at Locations A/5. In 1973, the highest fish catch percentage was at Locations A/5, and the lowest occurred at Locations C/19.

Total catches of individual species varied considerably over the three year period. Alewives were almost three times more abundant in 1971 than they were in 1973 and over five times more numerous in 1973 than in 1972. Yellow perch were twice as numerous in 1973 than in 1972 and over 11 times more abundant than in 1971. Catches of rainbow smelt were almost equal at comparable locations in 1973 and 1971, but smelt catches in 1973 were almost double the 1972 catch. Lake trout were much more abundant in 1971 than in 1973, although they were more numerous in 1973 than in 1972. Lake chubs were far more numerous in 1973 than in either 1971 or 1972. The total catch of white suckers in 1973 was more than twice the 1972 catch and more than five times the 1971 catch at comparable locations. The longnose sucker catch declined appreciably in 1973 over 1972, but catches in 1973 were slightly higher than those in 1971.

Seasonal patterns of abundance were observed for several species, but distribution within the study area was usually quite varied. Alewives were most abundant in May and June of 1971 and 1972, and in May, June, and July of 1973. Alewives were numerous at Locations A/5 in 1973 and 1971, but in 1972 they were most frequently taken at Locations C/19. Yellow perch were commonly collected from May through August in 1971 and 1972, and in 1972 perch were most numerous at Locations B/9. In 1973 yellow perch were also taken in substantial numbers from May through August, but the largest catch was taken in September, and perch caught were almost equally distributed between Locations A/5 and Locations B/9. The largest catches of smelt were taken in April of 1971 and 1973, and most commonly at Locations A/5. Smelt were taken most often in November at Locations C/19 in 1972 (sampling was not conducted in April).

Lake trout were most abundant at Locations B/9 (or equivalent) during all three years, but there was considerable fluctuation in their seasonal abundance within the study area. Several lake trout were taken in April of 1971 while only one was collected in April of 1973. This may have been the result of a three day storm on the lake prior to the April 1973 sampling. Substantial catches of trout were taken in May during each of the years, and in September of both 1972 and 1973. Largest catches of lake trout occurred in October during 1971 and 1973. Catches of lake trout in July and August of 1973, were considerably different from those in previous years. Twenty-seven lake trout were taken in July of 1971, while none were taken in July of 1973. Similarly, a large number of lake trout were taken in August of 1972 and only 12 were taken in August of 1973. A possible explanation for the lower numbers in 1973 may be that the water temperatures in the vicinity of the gill nets were colder in both 1971 and 1972 than in 1973. The highest fishing temperature in July 1971 was 6.6C lower than the lowest recorded in July 1973, and the highest temperature recorded in August 1972 was 1.9C lower than the lowest recorded in August 1973.

The largest number of lake chubs collected in 1973 were taken at Locations A/5, with a lower number almost evenly distributed between Locations B/9 and Locations C/19. However, in 1971, lake chubs were most numerous at the Site Location (B/9). In 1971, lake chubs were taken only in May and October, and in 1972, they were collected only in September; but in 1973, lake chubs were taken during all sampling periods.

White suckers were most abundant at Locations B/9 (or equivalent) during all three years, but their seasonal distribution varied substantially. The largest catches of white suckers occurred in October 1971 and May 1972 and September 1973. Longnose suckers were most numerous at Locations B/9 (or equivalent) in 1971 and 1972, but in 1973, most were taken at Locations C/19. The largest catches of longnose sucker followed the same pattern as white sucker catches in 1971 and 1972. The largest catch of longnose sucker in 1973 occurred in June.

Longnose dace were most commonly collected at Locations A/5 (or equivalent) during all three years. All but one were collected in June during 1971 and all but one were taken in September during 1972. During 1973, the largest catch was taken in September, but dace were collected in all months except November.

The remaining species were taken in insufficient numbers to determine any patterns of distribution or seasonal abundance from year to year.

IV. Summary and Conclusions

1. Water temperatures recorded on a given sampling date were similar among the three sampling locations. The highest temperatures recorded at gill net locations occurred in July (16.1C) and the lowest were recorded in April (2.3C). The highest temperatures at minnow seine locations occurred in August (17.5C) and the lowest were recorded in April (2.1C).

2. Monthly sampling in Lake Michigan with gill nets and minnow seines resulted in the collection of 24 different species of fish in 1973.

3. The total catch for the year was 5427 fish, of which alewife, yellow perch, rainbow smelt, lake trout, lake chub, slimy sculpin, white and longnose suckers and longnose dace were most abundant.

4. The addition of the 1 1/2 inch mesh gill net in 1973 resulted in the collection of younger individuals of larger species (yellow perch, coho and chinook salmon) and greater numbers of smaller species (alewife, rainbow smelt, lake chub).

5. Collections at the sampling locations to the north of KNPP (Locations A/5 produced greater numbers of fish than collections at the other sampling locations. A total of 2198 (40%) fish were collected from this area compared to 1615 (30%) fish from the locations directly offshore of the Plant (Locations B/9), and 1614 (30%) fish from the area to the south of the Plant (Location C/19).

6. Species which may have attempted spawning within the study area were alewife, yellow perch, rainbow smelt, lake trout, lake chub, slimy sculpin and longnose dace. Species believed to have spawned successfully

within the study area were alewife, rainbow smelt, lake chub, slimy sculpin, and longnose dace.

7. Total catches over the three year period varied considerably in terms of numbers, seasonal abundance and distribution. More fish were taken in 1971 than in 1972 or 1973, and more fish were taken in 1973 than in 1972. Individual species varied substantially in their seasonal abundance as well as in their distribution within the study area.

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Chapter 10

BOTTOM TOPOGRAPHY

Thomas V. Clevenger

PREOPERATIONAL THERMAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR KEWAUNEE NUCLEAR POWER PLANT

THIRD ANNUAL REPORT
January-December 1973

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I. Introduction

Additional bottom depth contour mapping of Lake Michigan was conducted in 1973 in the vicinity of the Kewaunee Nuclear Power Plant (KNPP). The objectives for making these studies were:

1. to provide supplemental data on depth soundings to that previously collected;

2. to describe more completely the bottom topography in the immediate area of the KNPP intake and discharge; and

3. to prepare a depth contour map which can be used as a basis for other studies conducted in Lake Michigan in the area of the Plant.

The relationship of bottom topography to lake current movements and predictive thermal plume configuration are discussed in Chapter 1 and 13, respectively.

II. Field and Analytical Procedures

Depth soundings were recorded along seven east-west transects on 26 June and 23 October, 1973 using a continuously recording fathometer aboard the commercial trawler, Chambers Brothers. Each transect was located with the aid of onboard ship radar. The ship's course was maintained along each transect by a compass bearing. The ship did not maintain a constant speed; therefore, the length of the transect on the fathometer printout does not ascribe to a uniform scale of distance. However, accurate distances from shore to each specific depth contour were determined by the ship's radar as each contour was identified.

On 26 June, depth soundings were recorded along four east-west transects (222 and 444 yd north and south of the Kewaunee Nuclear Power Plant) beginning at the 5-ft depth contour and continuing outward to the 20-ft depth contour. On 23 October, depth soundings were recorded while traversing from a depth of 5 to 40 ft along seven east-west transects (444, 333 and 222 yd south and north, and 111 yd south of KNPP).

Depths in 5-ft increments along each transect were plotted on a map of Lake Michigan showing the area in the immediate vicinity of the Plant. A bathymetric chart was constructed by connecting points of equal depth with a continuous line.

Radar and fathometer measurements were made using the following equipment:

1. Fathometer

Manufacturer - Kelvin-Hughes
Model - MS 28 F Marke II Mod. 1
Accuracy - ± Ft.
Max. Depth - 480 Fathoms

2. Radar

Manufacturer - Decca
Model - Super 101
Rated Accuracy - 1/5% of range
Ranges - 1/2:1 1/2:6:18 naut. mi.
Range marker - fixed

The mean water level of Lake Michigan for 1973 was established from data published by the U.S. Department of Commerce (1974). The lake elevation is based on the International Great Lakes Datum-1955, in which elevations are in feet above mean water level in the Gulf of St. Lawrence at Father Point, Quebec. All references to depth in this study are based on the 1973 mean lake elevation of 580.55 ft Mean Sea Level (MSL), Milwaukee, Wisconsin, Station No. 7057.

III. Results and Discussion

The irregularity of the bottom of Lake Michigan in the vicinity of KNPP was noted during the first year of preoperational monitoring in 1971 (Industrial BIO-TEST Laboratories, Inc. 1972). During the second year of preoperational study (Industrial BIO-TEST Laboratories, Inc. 1973), initial bottom topography mapping was performed and data from the 1972 study was combined with that gathered as a part of the present study to prepare the bottom contour map presented in Figure 10. 1.

Depth contours (isobaths) closely paralleled the outline of the shore in the vicinity of the Plant. The promontory on which KNPP is located was strongly reflected in all of the bottom contours plotted. Closer spacing of the isobaths on the southeast side of the promontory indicated that the overall bottom slope was steeper than that found on the northeast side of the promontory.

As noted from the continuous fathometer recordings (Figures 10.2 and 10.3), the bottom topography was very irregular, particularily between the 25- and 40-ft contours. This irregularity made it difficult to accurately locate the depth contours, and this should be considered when interpreting the bathymetric chart (Figure 10. 1). The 30-ft contour, for example, was located on the bathymetric map at 4200 ft from shore along the transect 111 yd south of the Plant, but could have been located anywhere between 4200 and 6650 ft from shore according to the fathometer chart (Figure 10. 3). This difficulty due to bottom irregularity was encountered on nearly all transects. Points of depth for determining each contour were located according to the general

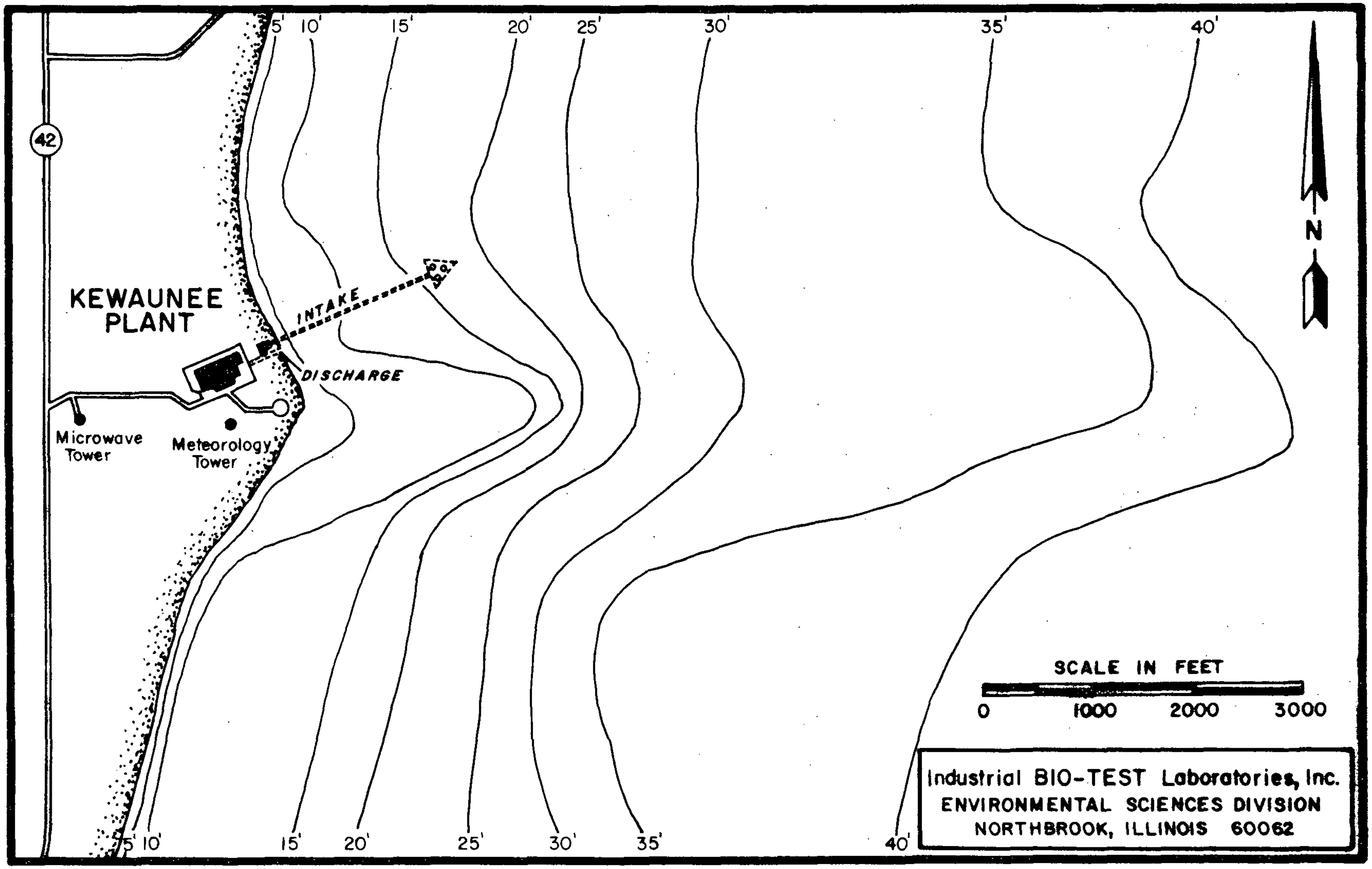

Figure 10.1 Bottom depth contours in the vicinity of the Kewaunee Nuclear Power Plant, Kewaunee, Wisconsin 1973. (Based on mean 1973 lake elevation of 580.55 ft MSL)

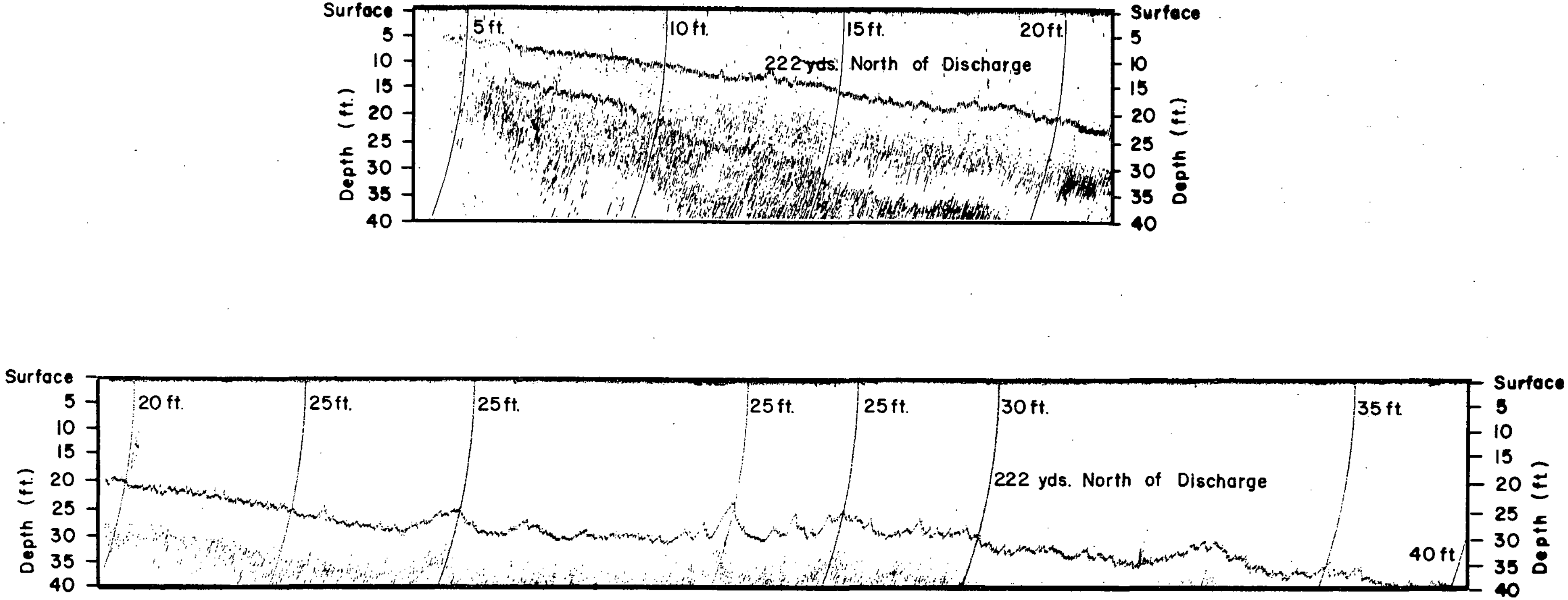

Figure 10. 2. Fathometer record of the Lake Michigan bottom topography along an east-west transect 222 yd north of the Kewaunee Nuclear Power Plant, 1973.

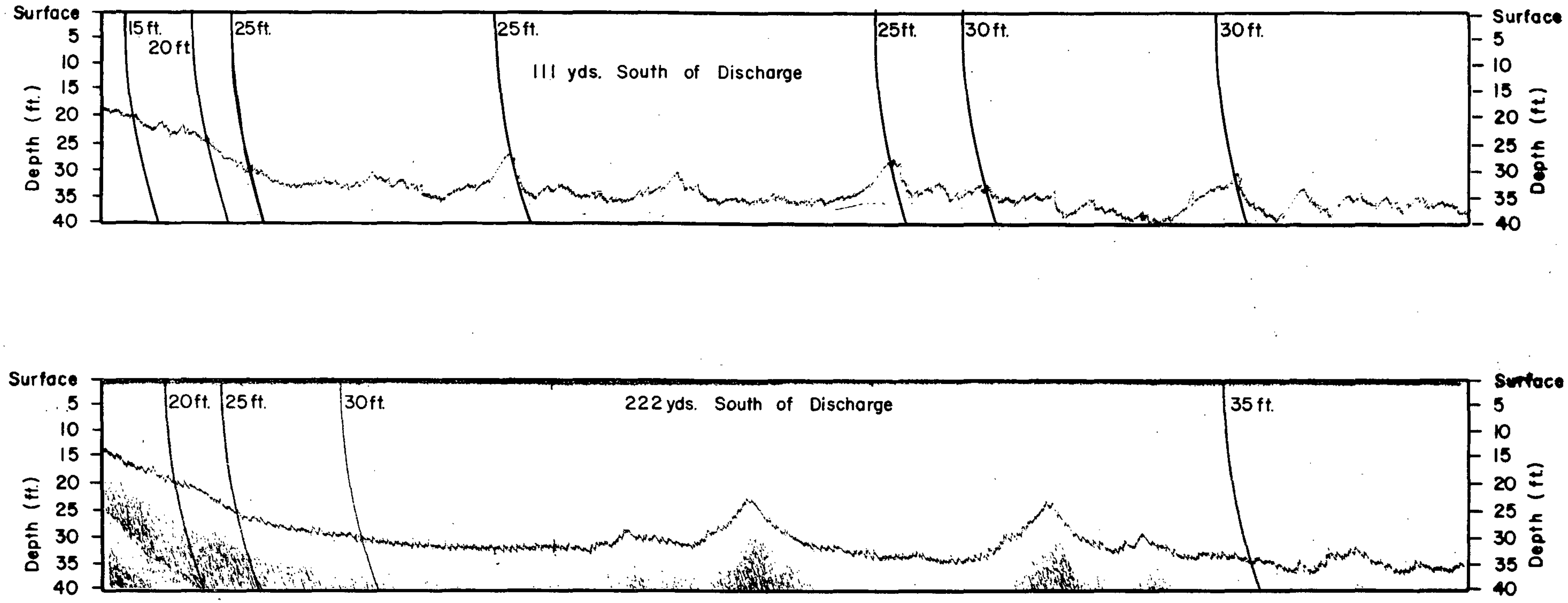

Figure 10. 3. Fathometer record of the Lake Michigan bottom topography along east-west transects 111 and 222 yd south of the Kewaunee Nuclear Power Plant, 1973.

slope of each transect and the relationship between points of equal depth along adjacent transects.

IV. Summary and Conclusions

1. In the vicinity of the Kewaunee Nuclear Power Plant, depth contours closely paralleled the outline of the shore.

2. The bottom topography is extremely irregular offshore from the Plant between the 25- and 40-ft depths.

3. Irregular bottom topography, particularly between 25 and 40 ft, made it difficult to locate depth contours exactly.

4. A detailed bathymetric map was prepared for the area in the immediate vicinity of the KNPP intake and discharge.

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Chapter 11

SEDIMENT CHARACTERIZATION

Joseph H. Rains

PREOPERATIONAL THERMAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR KEWAUNEE NUCLEAR POWER PLANT

THIRD ANNUAL REPORT
January-December 1973

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Chapter 11

SEDIMENT CHARACTERIZATION

Joseph H. Rains

I. Introduction

The Kewaunee Nuclear Power Plant (KNPP) utilizes a shoreline discharge which may alter the sediment characteristics in the immediate vicinity of the discharge either by scouring or by affecting sediment deposition. Sediment samples were collected near the mouth of the discharge twice during 1973 to establish the present, preoperational sediment character in terms of percent particle size composition. By comparison with future sediment analysis data, this baseline information will serve as a guide for determining the extent of possible erosion, deposition or alteration in sediment composition produced by Plant operation.

During the present study, the circulating water pumps at the Plant were essentially inoperative, although a minimal 6000 gpm flow was maintained throughout most of the year. Larger volumes were also occasionally discharged for short periods of time for testing purposes. Overall, these low volume, intermittent discharges would not be expected to have any noticeable effect on the sediments in the vicinity of the Plant discharge preoperationally.

II. Field and Analytical Procedures

Duplicate samples were collected 22 May and 17 October from five locations in the vicinity of the KNPP discharge (Figure 3, Introduction). Location 31 was established approximately 50 ft directly offshore from the mouth of the discharge. The other four locations were positioned in relation to Location 31, approximately 50 ft from each other, as illustrated in Figure 3, Introduction. Locations were established in relation to the mouth of the discharge rather than to water depth or distance from shore in order to minimize the effect of water level fluctuations.

Particle sizes were determined according to Method D422 (ASTM 1972). Sediments were separated into the following five particle size categories, and the percent composition of each size class was determined by weight:

Sediment Type	Size Class (mm)
Clay	<0.004
Silt	0.004-0.061
Fine sand	0.062-0.499
Medium to coarse sand	0.500-3.999
Gravel	>4.000

The general sediment types were described qualitatively through visual observations using the categories of Shepard and Moore (1955).

III. Results and Discussion

Fine sand composed at least 84% of all the sediment samples collected in the immediate vicinity of the Kewaunee discharge with one exception (Tables 11.1 and 11.2). Sediments in samples collected at Location 31 on 17 October contained an average of only 58% fine sand with 40% medium to coarse sand and gravel. Considering all sediment samples collected, fine sand composed an average of 90% of the total sediments. By combining the clay, silt, medium to coarse sand, and gravel data, these sediment types collectively accounted for an average of only 6% of the sediments in all samples except those collected at Location 31 on 17 October. Considering all sediment samples collected, the remaining sediment categories other than fine sand composed an average of 10% of the total sediments.

The cause of the shift in sediment composition at Location 31 on 17 October is not apparent at this time. One circulating water pump (275,000 gpm) was running at least part of the time on both 22 May and 17 October; therefore the shift in sediment composition could not be positively attributed to the discharge, but because of the position of Location 31 directly in front of the discharge structure, sediments there would likely be most susceptable to change due to intermittent pump activity.

Table 11.1. Percent composition of sediment types and general description of sediment samples collected in Lake Michigan near the mouth of the Kewaunee Nuclear Power Plant discharge, 22 May 1973.

Location No. and Replicate	Percent Composition of Sediment Type: Clay	Silt	Fine Sand	Medium to Coarse Sand	Gravel	General Description of Sediment Samples
30 A	1	0	92	7	0	Fine sand, brown
B	1	0	92	3	4	Fine sand, brown
31 A	1	0	93	5	1	Fine sand, brown
B	2	0	84	11	3	Fine sand, trace gravel, brown
32 A	1	0	98	1	0	Fine sand, brown
B	2	0	97	1	0	Fine sand, brown
33 A	2	0	98	0	0	Fine sand, brown
B	2	0	98	0	0	Fine sand, brown
34 A	2	2	89	4	3	Fine sand, brown
B	2	0	95	2	1	Fine sand, brown

Table 11.2. Percent composition of sediment types and general description of sediment samples collected in Lake Michigan near the mouth of the Kewaunee Nuclear Power Plant discharge, 17 October 1973.

	Percent Composition of Sediment Type					
Location No. and Replicate	Clay	Silt	Fine Sand	Medium to Coarse Sand	Gravel	General Description of Sediment Samples
30 A	1	0	98	1	0	Fine sand, brown
B	4	5	89	2	0	Fine sand, brown
31 A	1	4	54	12	29	Fine sand, trace gravel, brown
B	1	0	62	23	14	Fine sand, trace gravel, brown
32 A	1	0	97	2	0	Fine sand, brown
B	2	0	97	1	0	Fine sand, brown
33 A	1	6	92	1	0	Fine sand, brown
B	2	7	91	0	0	Fine sand, brown
34 A	2	0	98	0	0	Fine sand, brown
B	2	0	98	0	0	Fine sand, brown

IV. Summary and Conclusion

1. Fine sand composed an average of 90% of all the sediments collected from Lake Michigan in the immediate vicinity of the Kewaunee discharge for the two sampling periods.

2. Clay, silt, medium to coarse sand, and gravel collectively constituted the remaining 10% of the sediments.

3. On 17 October the sediments at the location directly offshore from the mouth of the discharge consisted of only 58% fine sand and 40% medium to coarse sand and gravel. The cause for this change in composition could not be determined.

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Chapter 12

SHORELINE EROSION

B. G. Johnson

PREOPERATIONAL THERMAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR KEWAUNEE NUCLEAR POWER PLANT

THIRD ANNUAL REPORT
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Chapter 12

SHORELINE EROSION

B. G. Johnson

I. Introduction

Shoreline erosion was one of the physical conditions to be documented and described in the vicinity of the Kewaunee Nuclear Power Plant (KNPP). The documentation was accomplished by means of aerial photographs taken during this third year of preoperational monitoring studies. The primary objectives for conducting this study in 1973 were:

1. To determine the present state of shoreline erosion;
2. To describe the seasonal variation in the relative degree of erosion occurring; and
3. To continue documentation of preoperational conditions relative to erosion in the vicinity of the KNPP.

II. Field and Analytical Procedures

Aerial photographs of the shoreline in the vicinity of the KNPP were taken quarterly in 1973, from a point approximately 2 1/4 miles north of the Plant to a point approximately 2 1/2 miles south of the Plant to determine the extent of shoreline erosion or deposition. The quarterly photographic dates were March 21, June 25, October 8, and December 28, 1973. The third quarter photographs, originally taken on September 24, were retaken on October 8 due to a camera malfunction on September 24 which resulted in poor film exposure.

Photographs were taken from a Cessna 172 Skyhawk rented from Green Bay Aviation, Austin Straubel Field, Green Bay. This high-wing aircraft was an excellent vehicle from which to take low altitude photographs because of its window configuration and maneuverability. During each photographic trip, photographs were taken from at least two altitudes and while flying either parallel to the shoreline or perpendicular to it. Altitudes were usually at 150-200 ft and at 350-400 ft while flying parallel to the shoreline and just offshore. This permitted close-up photos and observations of the beach and bluff zones to be made. Photographs were keyed to the same topographic features or landmarks during each quarter for comparative purposes. Photos taken perpendicular to the shoreline were taken from an altitude of 350-400 ft while crossing back and forth over the shoreline permitting photos and observations to be made up and down the shoreline.

In 1973, aerial photographs were taken on a quarterly basis for the first time during the preoperational period, although aerial photographs of the shoreline had been taken previously in both 1971 and 1972 (Industrial BIO-TEST Laboratories, Inc. 1972, 1973).

Records of water levels in Lake Michigan were obtained from the U. S. Department of Commerce (Department of Commerce 1974a, 1974b). Water levels served as a basis for making seasonal comparisons.

III. Results and Discussion

The Lake Michigan shoreline in the vicinity of the Kewaunee Nuclear Power Plant is characterized by a narrow beach composed of beach sand, which grades to gravel and rubble out from shore (Poff and Threinen 1966), backed by steep, unstabilized soil banks or bluffs ranging from 10 to 60 ft in height. Grass and tree cover on the bluffs is uncommon except in areas north of the Plant. Trees are common in ravines associated with the small tributaries entering Lake Michigan within the study area and this accounts for a number of fallen trees along the shoreline.

The shoreline in the vicinity of the KNPP is being subjected to severe erosion. The combination of rising lake level and storm activity facilitate erosion and provide a seasonal pattern. Davis et al. (1974) report that the most extensive losses are in the fall, and a less damaging period of erosion occurs after ice breaks up in the spring. During 1973, observations made quarterly indicated that the period of most extensive erosion occurred in the spring between March and June. This was evidenced by the presence in June of many new earth slides onto the beach as undercut banks collapsed (Figure 12.1). Further shoreline retreat, except for the collapsed material being eroded away, was not apparent during the rest of the year.

Seasonal changes due to erosion and deposition were most noticeable at the mouths of the small creeks flowing into Lake Michigan within the area being observed. The changing pattern of the outfall configuration reflects the dynamic nature of the lake's effect on the shoreline (Figures 12.2 and 12.3).

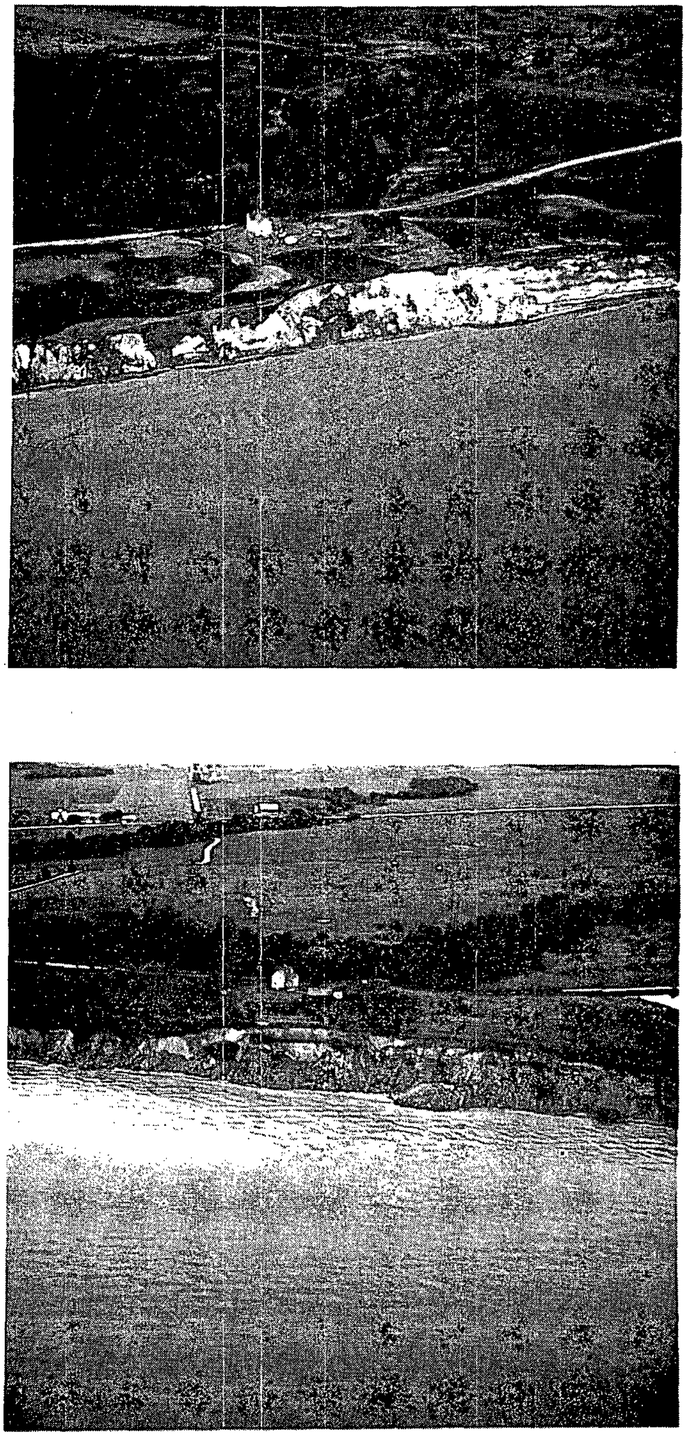


Figure 12.1. Shoreline 1 mi. north of KNPP showing collapse of bank between March and June 1974. (Upper photo taken March 21, lower photo taken June 25).

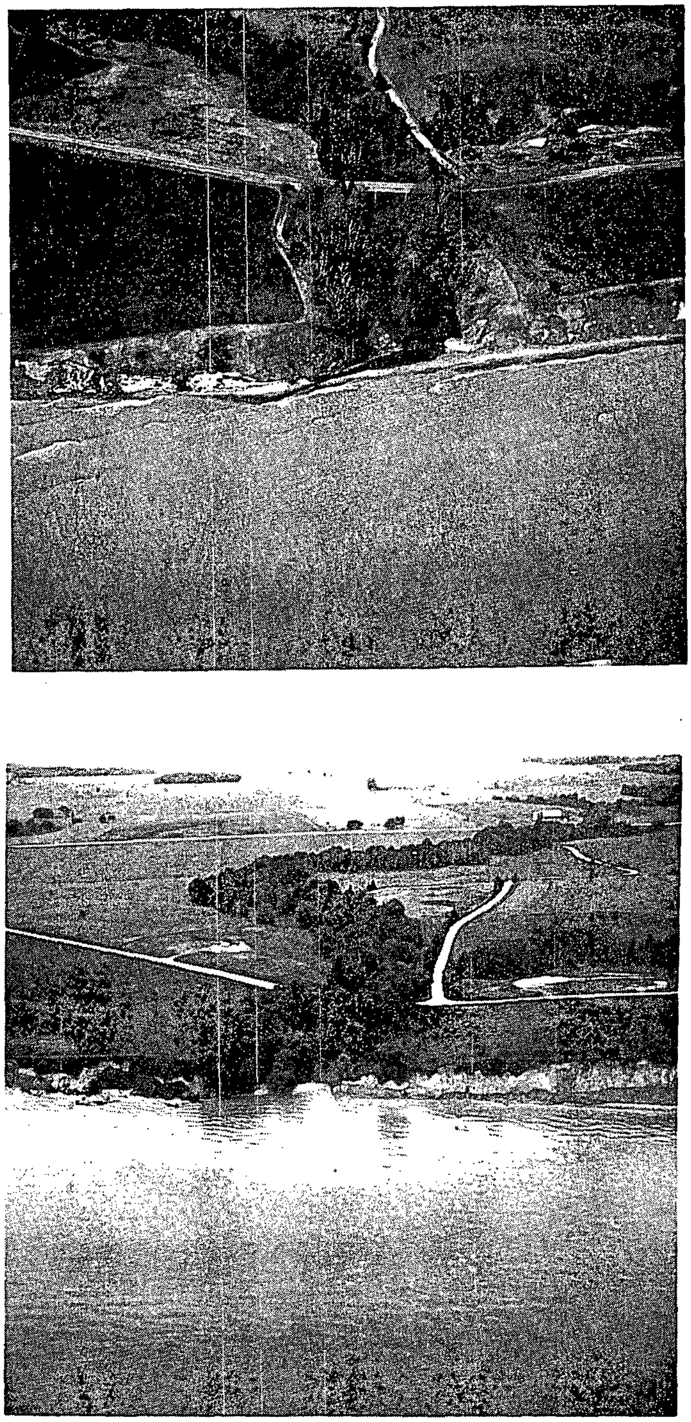
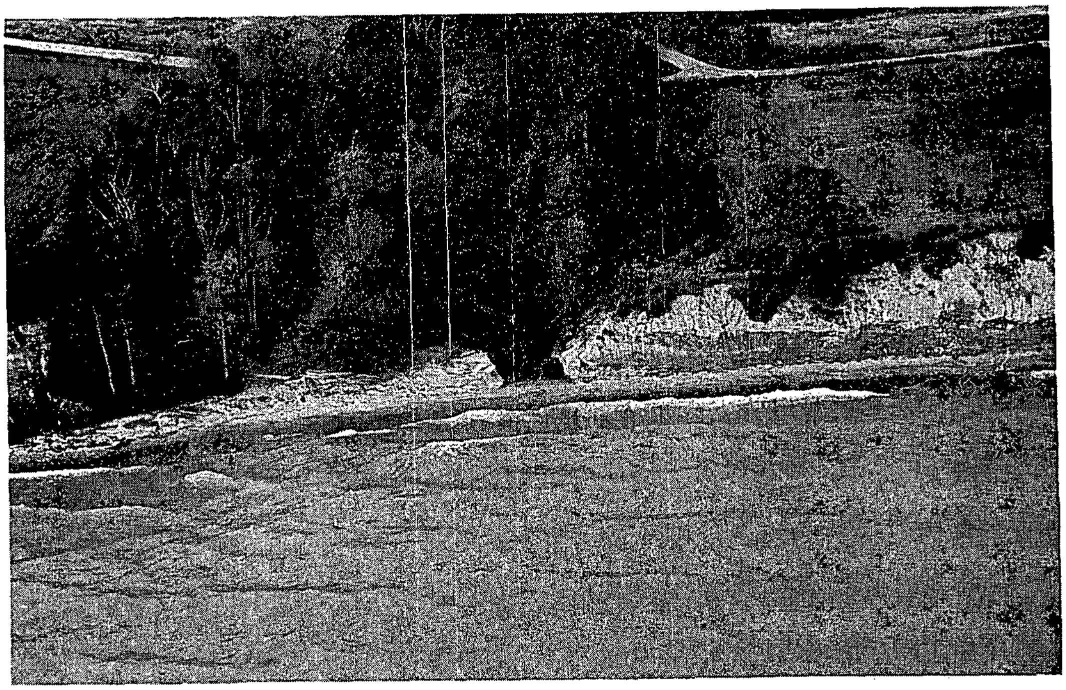


Figure 12.2. Seasonal erosion and deposition at mouth of creek located 3/4 mi north of KNPP. (Upper photo taken March 21, lower photo taken June 25).



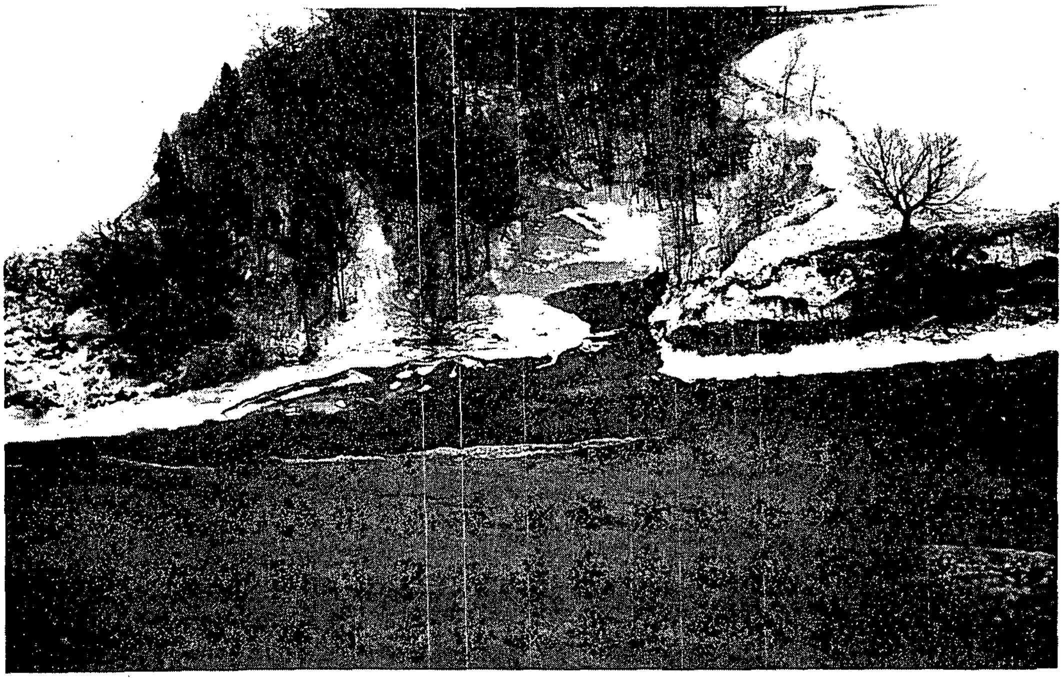


Figure 12.3. Seasonal erosion and deposition at mouth of creek located 3/4 mi north of KNPP. (Upper photo taken October 8, lower photo taken December 28).

Shore erosion is related to lake levels in Lake Michigan, and a significant correlation has been noted between the average rate of erosion and the average lake levels for periods of measurement (Seibel 1974). Lake Michigan water levels during 1973, for the periods when aerial photographs and observations were made, are shown in Table 12.1. Highest water levels were reached in June. Seasonal differences in shoreline and lake levels are apparent from photographs taken in the vicinity of the KNPP (Figures 12.4 and 12.5).

Considerable differences in local rates of erosion were apparent within the stretch of shoreline where observations were made during this study. In some areas the shoreline configuration remained unchanged while in others a considerable number of feet were apparently lost during 1973. No consistent pattern of erosion was determined in the area other than the fact that the majority of shoreline both north and south of the KNPP was in an extremely unstable condition as a result of the physical forces in effect (Figure 12.6).

Table 12.1. Lake Michigan water levels during 1973[a].

Photographic Date	Daily Mean	Monthly Mean	Daily Maximum	Daily Minimum
March 21	580.35	580.23	580.90	579.64
June 25	581.08	581.09	581.65	580.79
October 8	580.82	580.60	581.44	580.05
December 28	579.81	580.22	581.19	579.47

[a] Based on levels determined at Milwaukee, Wisconsin, Station Number 7057 (Department of Commerce 1974b).

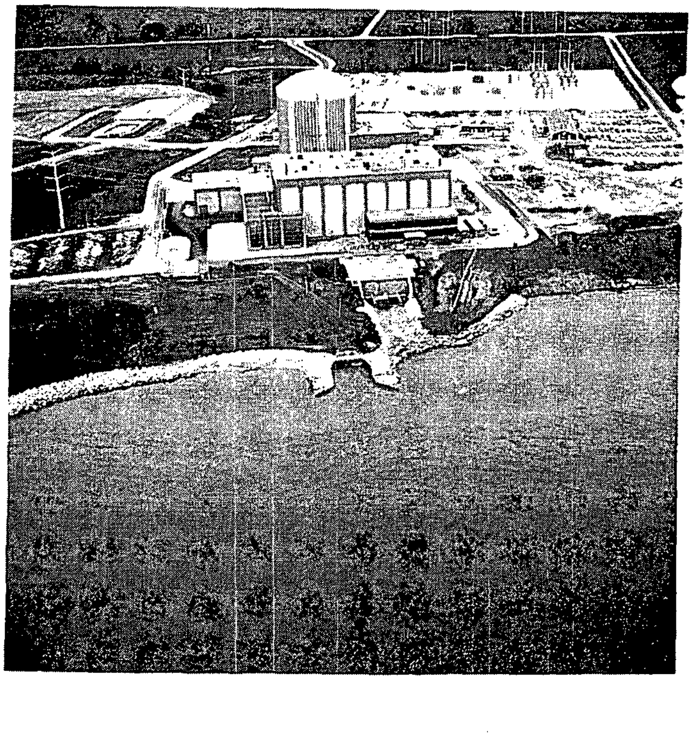
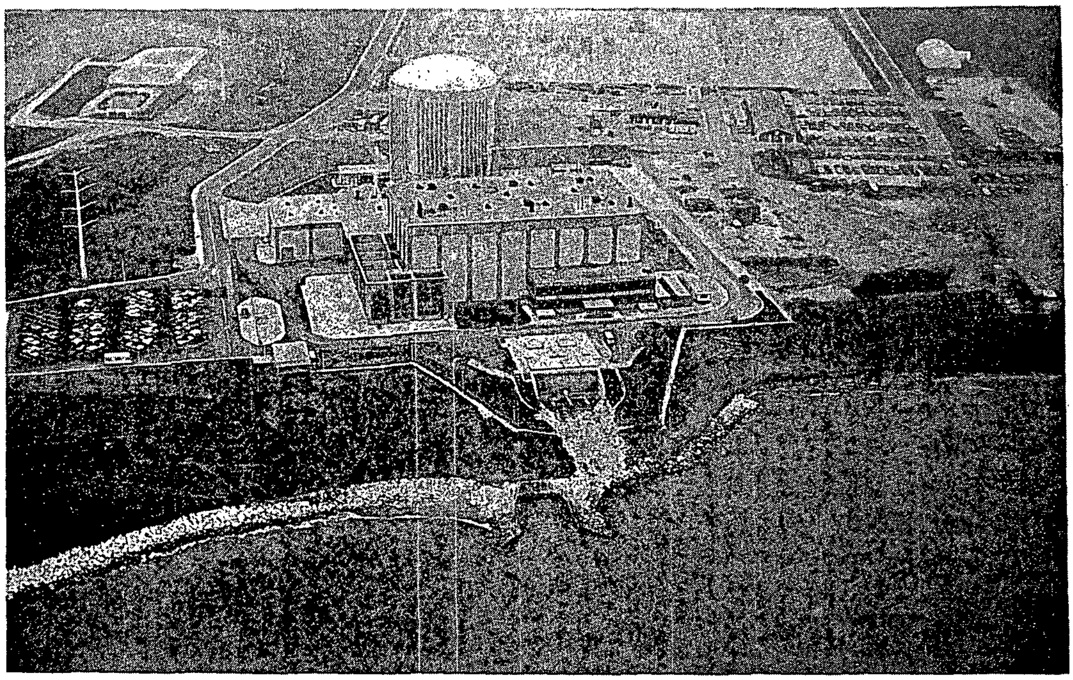


Figure 12.4. Shoreline and lake levels at KNPP. (Upper photo taken March 21, lower photo taken June 25).



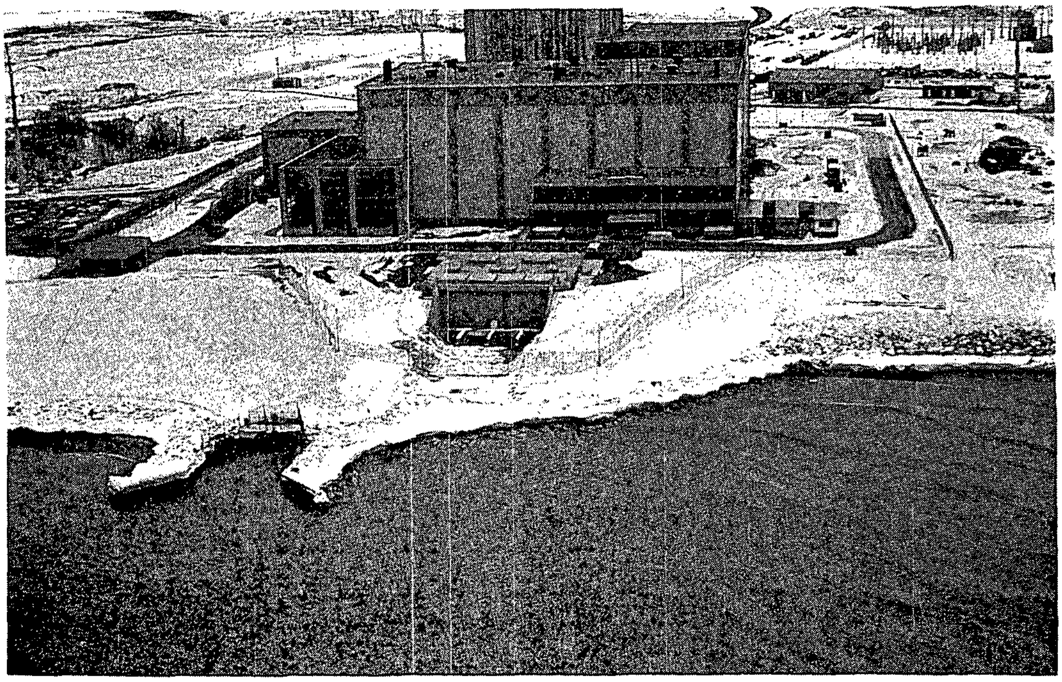


Figure 12.5. Shoreline and lake levels at KNPP. (Upper photo taken October 8, lower photo taken December 28).

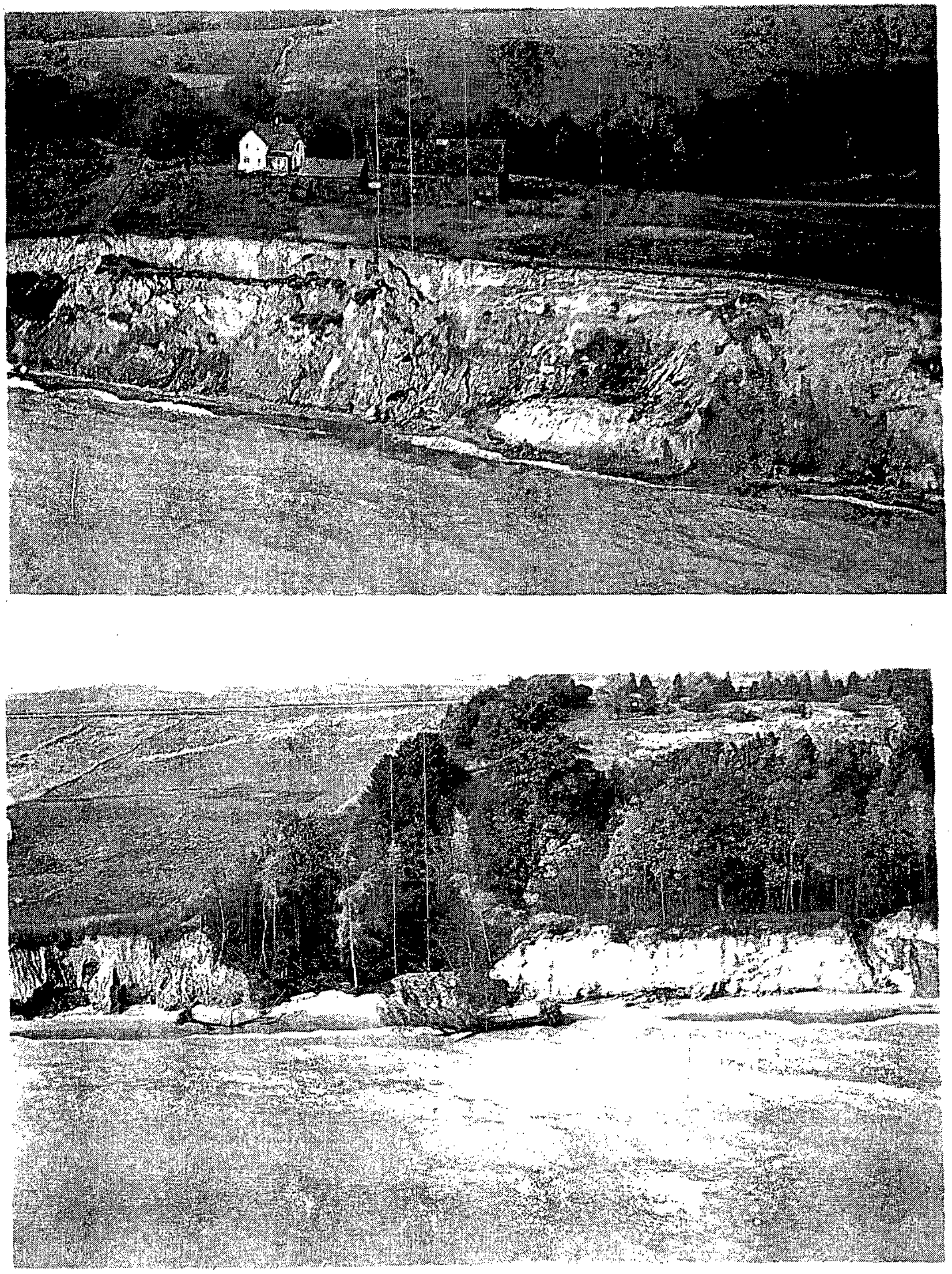


Figure 12.6. Shoreline in vicinity of KNPP characterized by steep, unstabilized soil banks, October 1974. (Upper photo taken 1 mi north of Plant, lower photo taken 1 1/4 mi south of Plant).

IV. Summary and Conclusions

1. The shoreline in the vicinity of the KNPP is being subjected to severe erosion.

2. The shoreline to the north and south of the KNPP site is generally characterized by a narrow beach backed by steep, unstablized soil banks ranging from 10 to 60 feet in height.

3. The shoreline at the KNPP is generally characterized by a narrow beach and gradual rise in elevation back away from the shore, with the shoreline in the immediate vicinity stablized by rip-rap.

4. Considerable differences in local rates of erosion were apparent within the stretch of shoreline where observations were made during this study.

5. The seasonal period of greatest change in shoreline configuration in 1973 was between March and June.

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Chapter 13

THERMAL PLUME MODEL

Floyd T. Lovorn

PREOPERATIONAL THERMAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR KEWAUNEE NUCLEAR POWER PLANT

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LIST OF SYMBOLS

Symbol	Definition
A_θ	Surface area contained within excess temperature isotherm θ
A_r	The aspect ratio of the discharge orifice
b_θ	Maximum width of area contained within the excess temperature isotherm θ
b_o	Horizontal width of discharge orifice
C_p	Specific heat at constant pressure
D	Vertical dimension of parcel of water containing excess heat
D_w	Depth of water at discharge orifice
F_o	$U_o/\sqrt{g\ (\Delta\zeta/\zeta)\ h_o}$, densimetric Froude number at the discharge orifice
g	Acceleration of gravity
h_o	Vertical width of discharge orifice
H	Vertical thickness of the thermal plume
$H_{1/2}$	Critical depth; depth at which excess temperature is one-half its value at the surface
$dH/d\xi$	Rate of vertical growth in the transition region between the discharge orifice and the offshore distance at which the water depth is equal to 1.5 $H_{1/2}$
K	Surface cooling coefficient
m	Coefficient relating b_θ and ξ_θ
n	Intercept of log-log relationship between the excess temperature ratio θ/θ_o and the relative distance from the orifice, $\xi_\theta/\sqrt{h_o b_o}$

LIST OF SYMBOLS (continued)

Symbol	Definition
q	Amount of excess heat contained in a parcel of water
Q	$U_o h_o b_o$, volume discharge rate
R	U_o/U_a
S_x	Offshore bottom slope
t	Time
T_a	Ambient water temperature
T_i	Intake water temperature
U_a	Ambient current speed
U_o	Discharge velocity at orifice
β	Slope of log-log relationship between the excess temperature ratio θ/θ_o and the relative distance from the orifice, $\zeta_\theta/\sqrt{h_o b_o}$
ζ_θ	Horizontal centerline distance to excess temperature isotherm θ
ζ	Density of ambient receiving water
$\Delta\zeta$	Density difference between heated water and ambient water
θ	Excess (above ambient) temperature
θ_o	Excess temperature at discharge orifice
ΔT	Temperature increase across condensers

Symbols Used in Flow Chart

a. Input parameters

BO	Same as b_o

LIST OF SYMBOLS (continued)

Symbol	Definition
HO	Same as h_o
DW	Same as D_w
QH	Heat dissipation rate
QQO	Same as Q
SX	Same as S_x
THETO	Same as θ_o
TAM	Same as T_a
TIN	Same as T_i
TYPE	Metric or English units
UA	Same as U_a
XS	Salt concentration of ambient water

b. Computed parameters

Symbol	Definition
QO	Same as U_o
FO	Same as F_o
AR	Same as A_r
SQRT (HO*BO)	$\sqrt{h_o b_o}$
$H_{1/2}$	Same as $H_{1/2}$
DH/DX	Same as $dH/d\xi$

CHAPTER 13

THERMAL PLUME MODEL

Floyd T. Lovorn

I. Introduction

Kewaunee Nuclear Power Plant (KNPP) is located within the Township of Carlton, Kewaunee County, Wisconsin. The Plant is operated by Wisconsin Public Service (WPS) and is scheduled to become operational early in 1974. The condenser cooling is accomplished by using once-through cooling water from Lake Michigan at a rate of 918 cubic feet per second (cfs), with a rise in water temperature (ΔT) across the condenser of 20F. In winter, the flow rate is reduced to 655 cfs with a ΔT=28F. The cooling system has a subsurface offshore intake and a surface, shoreline discharge.

Industrial BIO-TEST Laboratories, Inc. (BIO-TEST) has been conducting environmental studies since 1970 at KNPP to aid in evaluating the thermal effects of Plant operation upon the environment. This report presents the results of a study to develop a predictive model to describe the KNPP thermal discharge.

The specific objectives of this study were:

1. To conduct a literature search to select a practical state-of-the art thermal plume model that could be applied to the KNPP site; and

2. To develop and apply the thermal plume model to KNPP under various Plant operating and environmental conditions.

This report will:

1. Briefly describe the physical processes which control the dis-

tribution of excess (above ambient) temperature within a thermal plume discharged into Lake Michigan;

2. Assess the relative importance of each process for various segments of the plume;
3. Describe the thermal plume model developed for the KNPP;
4. Present thermal plume data to support the validity of the model; and
5. Present the numerical results of the application of this model to the heated discharge from the KNPP for various Plant operating and environmental conditions.

II. Field and Analytical Procedures

A. Literature Search

As part of this study, a literature search was conducted to select a practical state-of-the-art thermal plume model that could be applied to the KNPP site. From this literature search, models selected for further consideration were Koh and Fan (1970), Stolzenbach and Harleman (1971), Barry and Hoffman (1972), Pritchard and Carter (1972), Pritchard (1973), and Waldrop and Farmer (1973). Each of these models are documented and available as a computer program.

The model developed for application to the KNPP site is based on Pritchard's 1973 model. The computer program was written by Argonne National Laboratories Environmental Sciences,with modification by BIO-TEST.

The remaining models are not suitable for application to the KNPP site. The model by Koh and Fan is qualitative in its application to most existing discharge structures because it is two-dimensional with vertical entrainment only. The temperature and velocity decay too rapidly in the Stolzenbach and Harleman model, and the thermal plume is too wide. In addition, the numerical solution technique seems to be unrealistically dependent on "error criteria" (Paddock and Policastro 1972). Pritchard and Carter did not adequately account for the effect of bottom topography and ambient currents. A finite difference numerical model was developed by Waldrop and Farmer to predict the distribution of freshwater discharged into salt water. Time constraints did not allow appropriate modifications to be made to this model for application to thermal discharges. The model developed by Barry and Hoffman was unsatisfactor for predictive purposes because it required environmental input parameters which are difficult to determine a priori.

B. Physical Processes

Three physical processes are important in reducing the excess temperature (defined as the number of degrees above ambient temperature due to a thermal discharge). These are:

1. initial dilution through entrainment of ambient waters into the discharge flow;
2. dilution through natural mixing or turbulent diffusion into the cooler ambient water; and
3. loss of heat to the atmosphere (surface cooling).

Initial dilution through entrainment is a mechanical mixing process. The intensity of this process is a function of the non-dimensional Froude number, and that region of the plume in which it is important is often called the near field. The Froude number, F_o, is a measure of the ratio of the inertia force to the gravity force. The inertia force is associated with the excess momentum of the discharge and hence is proportional to the discharge velocity, U_o. For a heated discharge, the gravity force is associated with the buoyancy of the discharge and hence is proportional to $g(\Delta\zeta/\zeta)H$, where g=acceleration of gravity, ζ =density of receiving water, $\Delta\zeta$=difference in density between plume and receiving water, and H=vertical thickness of plume. By definition:

$$F_o = U_o / \sqrt{g(\Delta\zeta/\zeta)H} \qquad (1)$$

This is called more specifically the densimetric Froude number to distinguish it from the case in which buoyancy forces are not present.

A higher F_o means more rapid dilution by entrainment. A lower F_o means a decreased rate of dilution by entrainment, an increased width due to buoyancy forces spreading the plume laterally, and a thinner plume due to the rising of heated water.

Natural mixing is unimportant near the point of discharge because the turbulence associated with the discharge jet overwhelms any ambient turbulence. As the discharge jet entrains ambient water, the excess momentum and excess temperature of the plume decrease to the point where ambient turbulence (natural mixing) becomes important in effecting any further dilution. In this region of the plume, often called the far field, other processes which enhance mixing (e.g. the shear in wind driven currents and mixing due to waves) become important. After the plume is cooled by dilution, there still exists some excess heat. This heat will be lost to the atmosphere through the air-water interface.

The rate of heat loss to the atmosphere by a parcel of water containing excess heat is often modeled satisfactorily by the equation (Pritchard 1973, Edinger and Geyer 1965):

$$dq/dt = -K\,\theta \qquad (2)$$

where dq/dt=rate of heat loss per unit area (q=excess heat, t=time), K=surface cooling coefficient, θ=excess temperature. That is, for a parcel of water containing excess heat, the rate of heat loss is proportional to the excess temperature of the parcel. The surface cooling coefficient, K, depends primarily on wind speed, secondarily on natural water temperature, and, within the range of excess temperature normally encountered, only to a third order on excess temperature (Pritchard 1973, Edinger and Geyer 1965). In the KNPP model to be discussed later, surface cooling is based on this equation and is applied as a corrective term to the excess temperature distribution determined by dilution only.

C. Dilution vs. Surface Cooling

The relative importance of dilution (entrainment plus natural mixing) and surface cooling can be ascertained by comparing particular cases designed to promote one process or the other. This comparison is made in Table 13.1.

The three cases in Table 13.1 are based on examples given by Pritchard 1973. Computations for each case are for a hypothetical 1000 MWe power plant rejecting 7.02 x 10^9 BTU/hr at 1560 cfs with an excess temperature at the discharge orifice (θ_o) of 20F. Ambient temperature is assumed to be 60F and wind speed equal to 10 mph.

Case I in Table 13.1 is for surface cooling only. It is theoretical and only relevant as a comparison, since any discharge will be cooled by dilution to some extent. Areas computed for this case are based on a solution to equation (2). Since $q=C_pD\theta$, where C_p=specific heat and D=depth of a layer of water containing excess heat, equation (2) can be solved to give:

$$\theta = \theta_o e^{-Kt/C_pD} \qquad (3)$$

In the absence of any mixing with the receiving water, the following formula applies (Pritchard and Carter 1972):

$$t/D = A_\theta/Q \tag{4}$$

where A_θ=horizontal area of an isotherm of excess temperature θ, and Q=volume discharge rate. Thus,

$$\theta = \theta_o e^{-KA\ /C_pQ} \tag{5}$$

or

$$A = \frac{C_pQ}{K} \ln(\theta_o/\theta) \tag{6}$$

The areas within all isotherms are large; however, of particular interest for later comparison is the predicted 1119.3 acre area within the 10F excess temperature isotherm.

Case II shown in Table 13.1 is designed to promote a minimum of dilution by entrainment and natural mixing. It has an initial densimetric Froude number of 2.54. Though designed for a minimum of dilution, the area within the 10F isotherm is only 25.2 acres which is substantially reduced from that of Case I. In Case II, surface cooling in addition to dilution does not significantly affect the area within the 10F isotherm, but it does substantially reduce the area within the 5F, 3F, and 2F excess temperature isotherms. For example, the area within the θ=3F isotherm for dilution is 79,120 acres. The addition of surface cooling reduces this area to 6305 acres.

Case III is designed to promote rapid dilution by entrainment and natural mixing. It has an initial densimetric Froude number equal to 11.34. In this case, it is apparent that the addition of surface cooling to dilution does not

Table 13.1. Comparative importance of dilution and surface cooling processes for various thermal plumes. Case I-no dilution. Case II-small dilution. (F_o=2.54). Case III-rapid dilution (F_o=11.34). A_{sc}=Area with surface cooling only. A_d=Area with dilution only. A=Area with dilution plus surface cooling.

Excess Temperature (°F)	Case I	Case II		Case III	
	A_{sc} (acres)	A_d (acres)	A	A_d (acres)	A
10	1119.3	25.3	25.2	0.5	0.5
5	2341.6	8727	4238	9.2	9.2
3	3263.2	79120	6305	46.2	46.0
2	3997.5	177664	6317	120.3	119.4

significantly affect the areas of isotherms of excess temperature greater than 2F. For example, the area within the θ=2F isotherm for dilution only is 120.3 acres. The addition of surface cooling reduces this area to only 119.4 acres.

Thus as the contribution of dilution by entrainment and natural mixing to the cooling process is increased (as related to the increasing Froude number), the effect of surface cooling becomes important only in the larger areas of small excess temperature.

D. Thermal Plume Model

The thermal plume model developed for KNPP is based on the 1973 model by Pritchard. Pritchard characterizes this model as "semi-theoretical, semi-emperical." The technique used to develop the basic model (multivariant analysis) is one of correlating several dependent (b_θ, ξ_θ, β, n, m, $H_{1/2}$, $dH/d\xi$) and independent (b_o, S_x, R, F_o, D_w, A_r, θ_o) variables (see List of Symbols) and using these correlations to formulate the predictive equations.

The KNPP model is based on a fit of an excess temperature isotherm (θ) vs. horizontal distance to this isotherm (ξ_θ) relationship of the form:

$$\xi_\theta / \sqrt{h_o b_o} = n \, (\theta/\theta_o)^{-\beta} \qquad (7)$$

and a maximum horizontal width (b_θ) vs. horizontal distance (ξ_θ) relationship of the form:

$$b_\theta = b_o + m \, \xi_\theta \qquad (8)$$

to extensive observational data from model basin tests, plume tests, and field surveys.

On the basis of multivariant analysis, Pritchard related n, m, and β to F_o, D_w, S_x, R, and A_r. That is:

$$n = n(F_o, D_w, S_x, R)$$

$$m = m(F_o, D_w, S_x, R)$$

$$\beta = \beta(F_o, A_r, D_w, S_x, R)$$

Beyond a transition region, the model characterizes the plume in its third dimension (depth) by the critical depth, $H_{1/2}$. This is the depth at which the excess temperature decreases to one-half its surface value. Pritchard's observations indicate that this depth is constant for a given A_r, b_o, and F_o, and the best fit relationship is:

$$H_{1/2}/\sqrt{h_o b_o} = 0.3\ (A_r)^{1/4}(F_o)^{3/4} \qquad (9)$$

Whenever h_o is less than $H_{1/2}$, the model specifies a vertical growth rate ($dH/d\xi$) in the transition region between the discharge structure and the horizontal position at which the water depth reaches 1.5 $H_{1/2}$. The best fit relationship for this growth rate is:

$$dH/d\xi = 0.278\ (A_r)^{1/8} e^{-6.4 F_o^{-0.4}} \qquad (10)$$

When the thermal plume is depth limited, the model predicts the horizontal position at which the plume begins to interact with the bottom and, in the case of a sloping bottom, the position at which the plume separates from the bottom.

The centerline excess velocity of the plume is assumed to decay at the same rate as the excess temperature. This is probably a reasonable assumption only in the case of an unbent plume. Methods have been developed for calculating a trajectory for a bent plume (Motz and Benedict 1972, Elliott and Harkness 1973); however, specifying adjustable parameters in the trajectory equations requires a fit to field measurements of actual KNPP thermal plumes. At present, the model predicts the centerline distance to an isotherm, but not the trajectory of the centerline.

The KNPP model treats the following cases:

a. Unbent plume, not depth limited (zero ambient current, no bottom interaction);

b. Unbent plume, depth limited (zero ambient current, bottom interaction);

c. Bent plume, not depth limited (ambient current, no bottom interaction); and

d. Bent plume, depth limited (ambient current, bottom interaction).

The pertinent equations for each case for cooling by dilution only are found in Pritchard (1973). There are some corrections to these equations (Policastro, personal communication) which have been incorporated into the model. The technique discussed in Pritchard (1973) for surface cooling correction was not applied successfully to areas of small excess temperatures. Thus, the area of the plume is corrected for surface cooling using the technique of Pritchard and Carter (1972). Where comparable, the latter method made conservative corrections compared to the former. Furthermore, the Lake Hefner heat exchange equation (Edinger and Geyer 1965) is used in preference to the table of surface cooling coefficients provided by Pritchard and Carter (1972). This probably increases the conservatism of the surface cooling correction since the Lake Hefner equation does not account for increased evaporation due to atmospheric convection over a heated discharge. Figure 13.1 is a flow chart for the computer program of the KNPP thermal plume model.

E. Justification for Use of the Model

The validity of any numerical model must be tested by comparison of predicted and observed distributions. In particular, the present model must be compared with temperature distributions not used in its formulation.

Pritchard (1973) presents comparisons with field data from Pilgrim Nuclear Power Station in Cape Cod Bay and Ginna Nuclear Power Station on Lake Ontario, and with laboratory data from the CBI-Hydronautics test flume. He notes that the comparisons "suggest that any error in the predictive model is on the conservative side." However, for a bent, shallow water plume the prediction of centerline distances to isotherms is exceptionally good. Pritchard's figures for this case have been reproduced in Figures 13.2 and 13.3.

Additional comparisons have been made with data collected by Argonne National Laboratories (ANL) for the thermal plume at Point Beach. Predictions were made based on input data provided by ANL and plotted against centerline temperatures and areas as determined by ANL. These comparisons are presented in Figures 13.4 and 13.5.

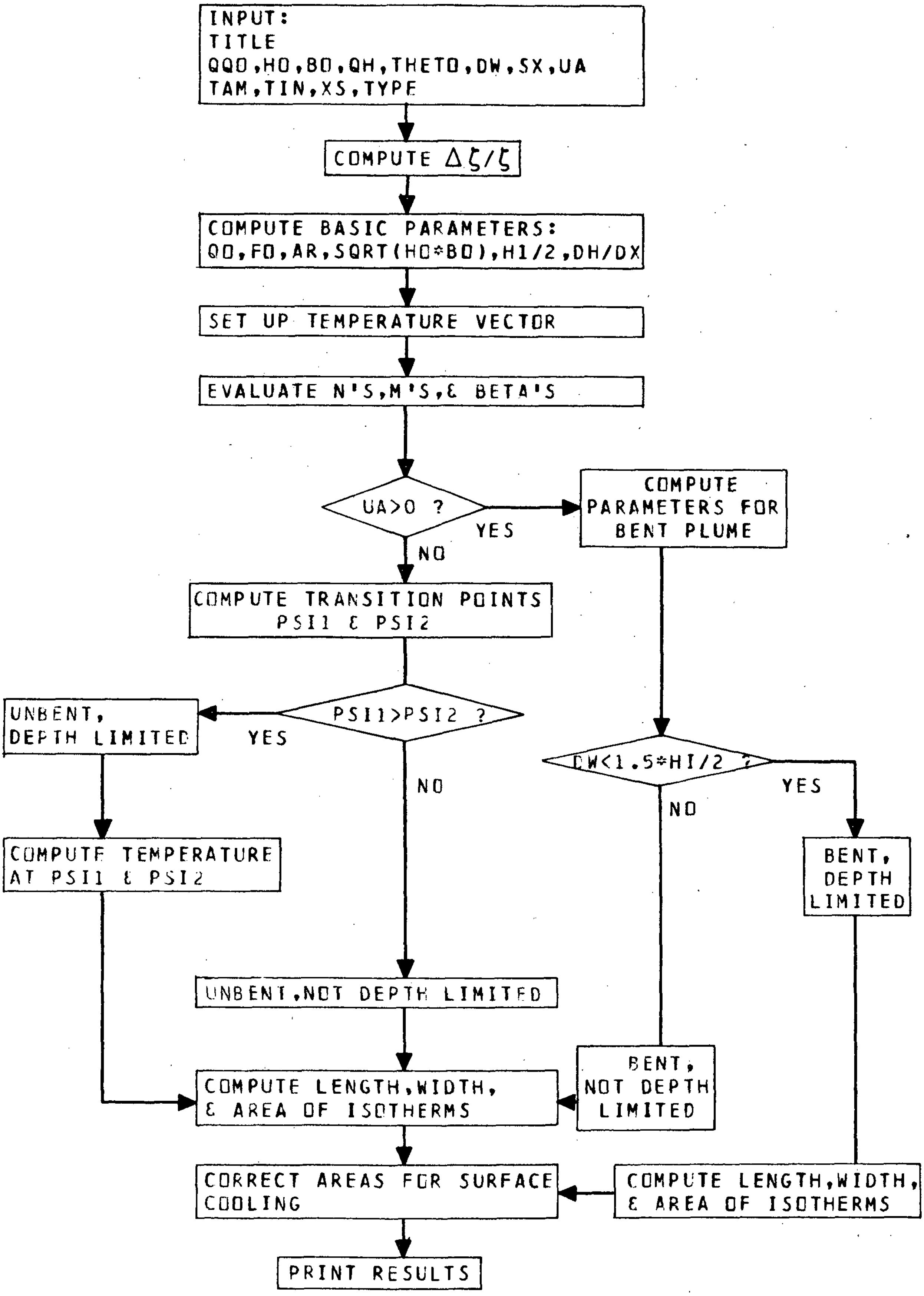

FIGURE 13.1 FLOW CHART OF COMPUTER PROGRAM FOR THERMAL PLUME MODEL.

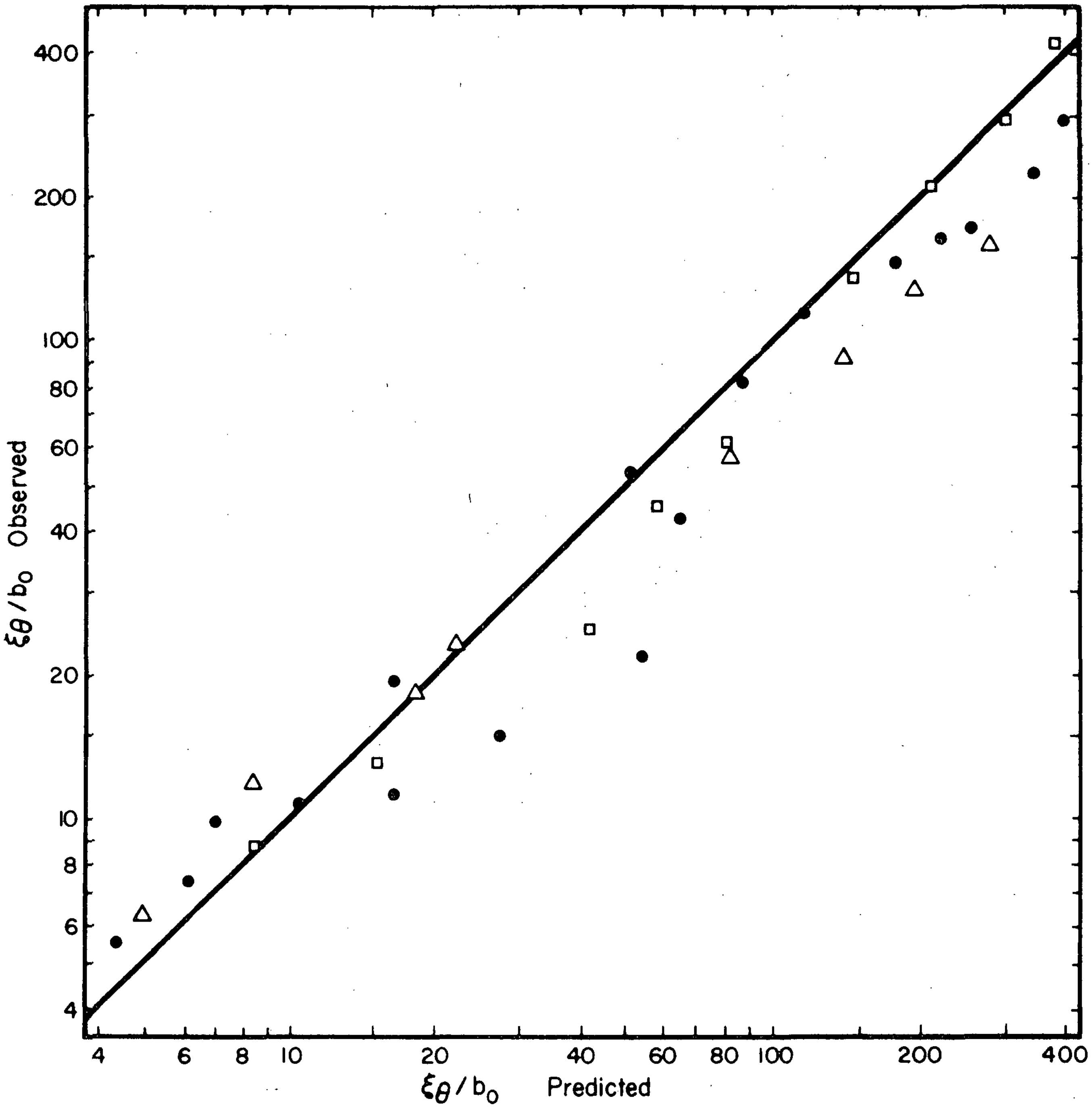

Figure 13.2 Comparison of observed vs. predicted lengths of bent, shallow water thermal plumes as defined by specified isotherms of excess temperature for measurements made in CBI-Hydronautics test flume (from Pritchard 1973). Conservative predictions are to the right of the solid line.

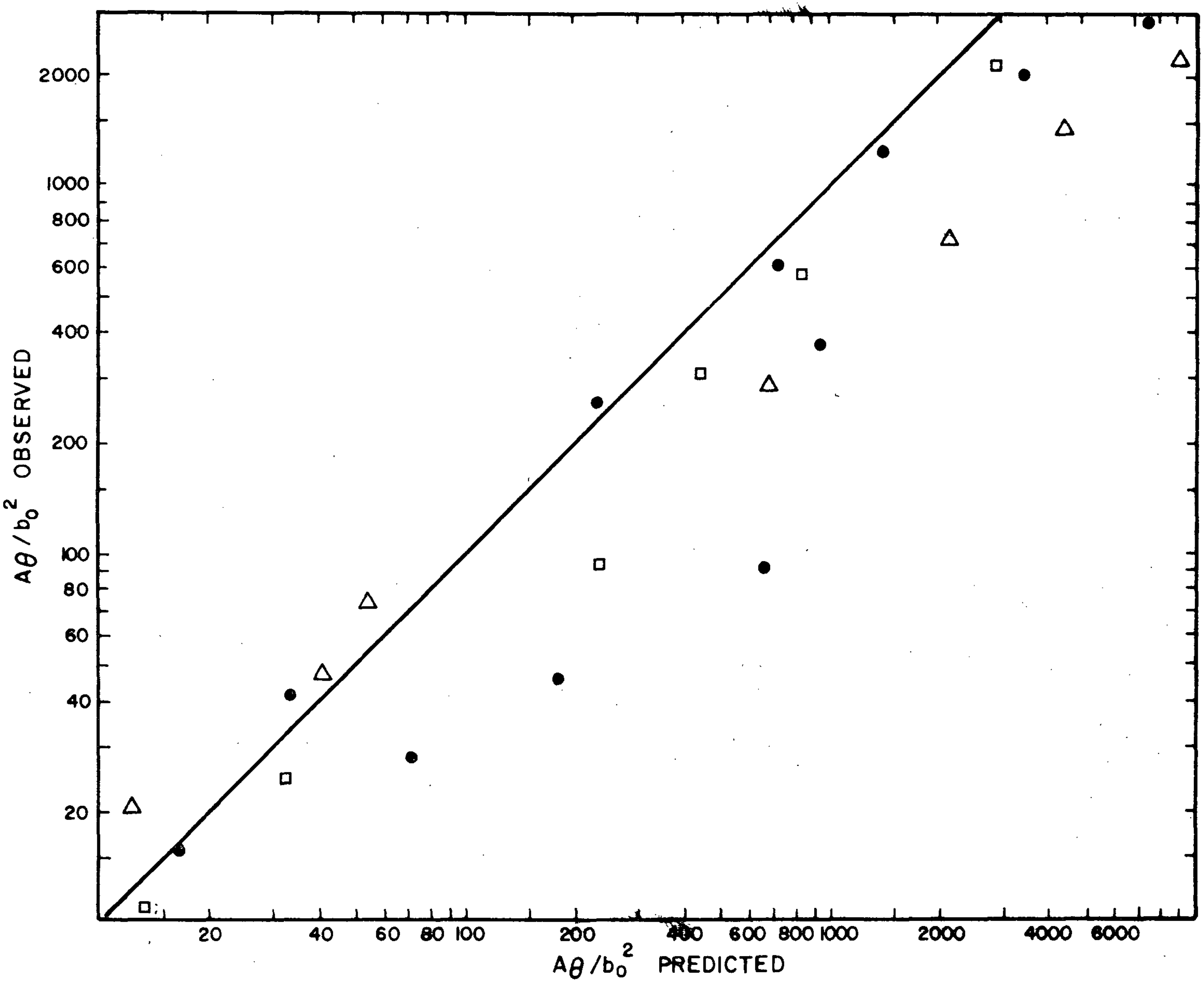

Figure 13. 3 Comparison of observed vs. predicted areas of bent, shallow water thermal plumes as defined by specified isotherms of excess temperature for measurements made in CBI-Hydronautics test flume (from Pritchard 1973). Conservative predictions are to the right of the solid line.

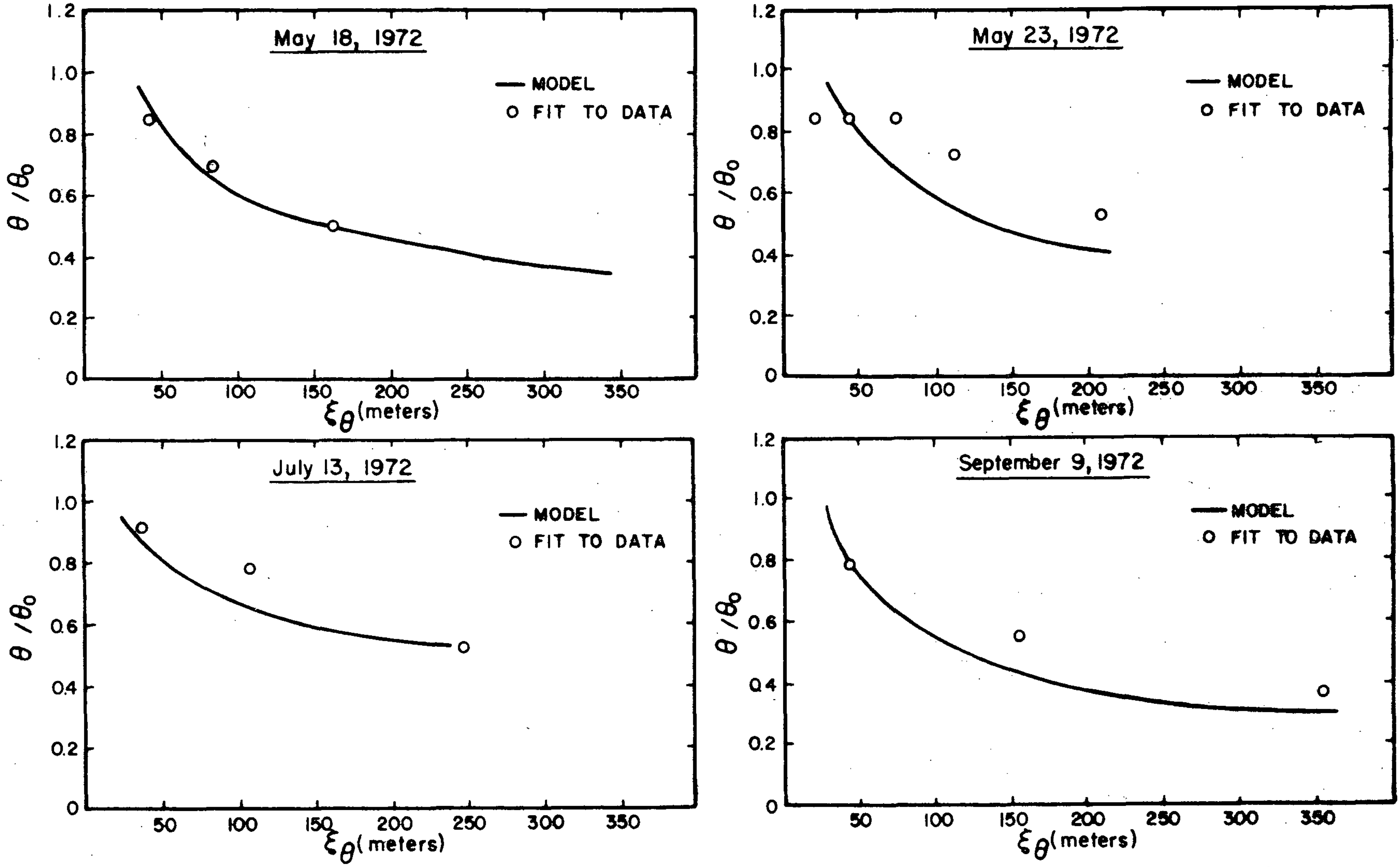

Figure 13.4 Comparison of thermal plume model predictions with observed excess temperature vs. distance from discharge for data from Point Beach thermal plume (Data collected on indicated dates by Argonne National Laboratories. From Paddock and Policastro 1972).

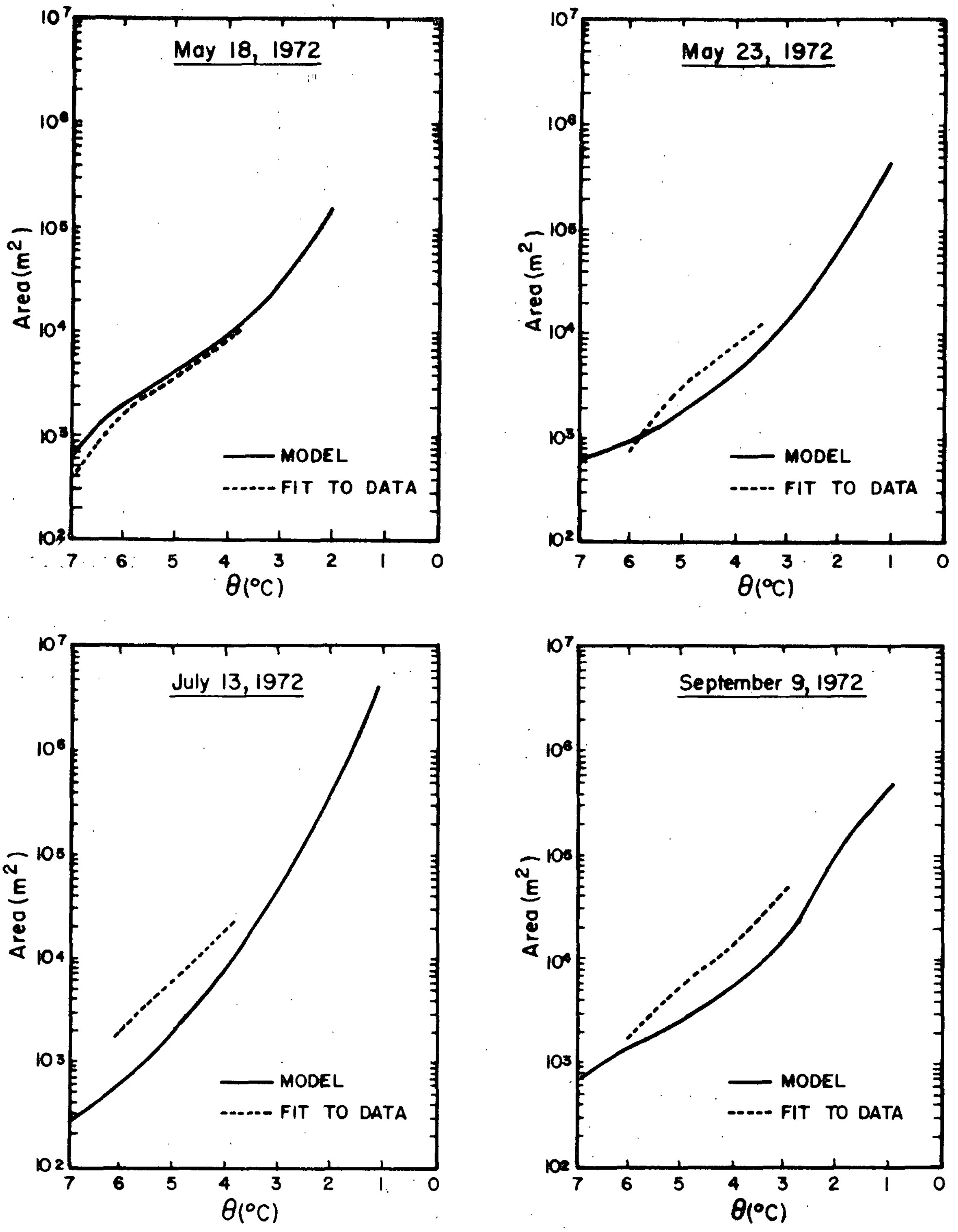

Figure 13.5 Comparison of thermal plume model predictions with observed areas vs. excess temperature for data from Point Beach thermal plume (Data collected on indicated dates by Argonne National Laboratories. From Paddock and Policastro 1972).

Compared to the ANL field data, the predictions are often optimistic. However, these data were taken within a distance of about 30 discharge widths (ξ_θ/b_o=30) from the discharge structure. Pritchard's comparisons also show the model to be optimistic in this region. No data were taken for comparison with the far field characteristics of the plume.

In Table 13.2, predictions of the KNPP thermal plume model are compared with predictions of a phenomenological thermal plume model developed by Elliott and Harkness (1972). A phenomenological model is one which relies on a statistical analysis of the measurements of the phenomenon as a whole rather than the basic equations of physics to describe the processes. For the specified plant operating and environmental conditions, the phenomenological model is conservative with respect to the KNPP thermal plume model developed by BIO-TEST as a part of the present study.

Table 13.2 Comparison of predictions by the Kewaunee Nuclear Power Plant (KNPP) thermal plume model with predictions by a phenomenological model (Elliott and Harkeness 1972) for a volume discharge rate equal to 918 cfs, an initial temperature rise of 20F, zero wind speed, and zero ambient current.

Excess Temperatures (°F)	Area Phenomenological Model (acres)	Area KNPP Model (acres)
15	5.6	0.3
10	57.5	1.9
5	224.6	47.3
3	343.1	191.4
2	415.9	443.7

III. Results and Discussion

The application of the model to KNPP will be addressed with respect to a number of topics listed below, which are considered to be the significant environmental or plant operating conditions for the KNPP site. All of the Tables referenced in this section are found in Appendix 9-A and run consecutively from Table 1 through Table 18.

A. Bottom Topography

Bottom topography is included in the KNPP model to the extent that a constant bottom slope (S_x) is an input parameter to the model. To evaluate the effectiveness of the model's treatment of bottom topography, the results of changing the bottom slope are presented in Tables 1, 2, and 3. Based on bathymetric profiles, a bottom slope of 1/100 is used in all subsequent thermal plume predictions.

Decreasing S_x (Table 1) increases the width of the plume, increases the distance to each isotherm, and thus increases the predicted area of each isotherm. The plume is also depth limited for a greater distance. Physically this is a result of a cutoff of the vertical entrainment through the bottom of the plume. In addition, some of the excess momentum is lost due to bottom friction and is not available to induce lateral entrainment.

Increasing S_x (Table 2) results in less bottom interaction which permits a greater amount of entrainment and a consequent reduction in lengths, widths, and areas.

For summer conditions, where the intake temperature (T_i) is equal to the ambient temperature (T_a), and where S_x=1/100, the plume is depth limited for an offshore distance of approximately 1300 ft (Table 3).

B. Submerged Promontory

It has been proposed (Atomic Energy Commission 1972) that for a northward current an eddy may develop on the north side of the submerged promontory just south of and adjacent to the site (Figure 13.6). This eddy may define an area of reduced exchange with ambient water. A thermal plume discharged into this area could be expected to locally raise the ambient temperature. In turn, this water of increased ambient temperature would be entrained into the plume and affect its size.

The size of the eddy, and thus the area of locally increased ambient temperature, can be estimated from the bathymetry shown in Figure 13.6 to be approximately 2500 ft in diameter (or 113 acres). To estimate the increase in mean temperature of this area requires a knowledge of the amount of heat advected through the area by the plume, an estimate of the amount of exchange between eddy water and cooler ambient water outside the eddy, and the mixing characteristics within the eddy. At present, the best source for this information would be a field study designed to investigate the dynamics of the eddy, if it exists. To estimate the eddy effect on plume size requires that the model deal with horizontal temperature gradients, since the thermal plume would transit an area of locally increased ambient temperature (the eddy) into cooler ambient water outside the eddy. This is beyond the present capability of the KNPP model.

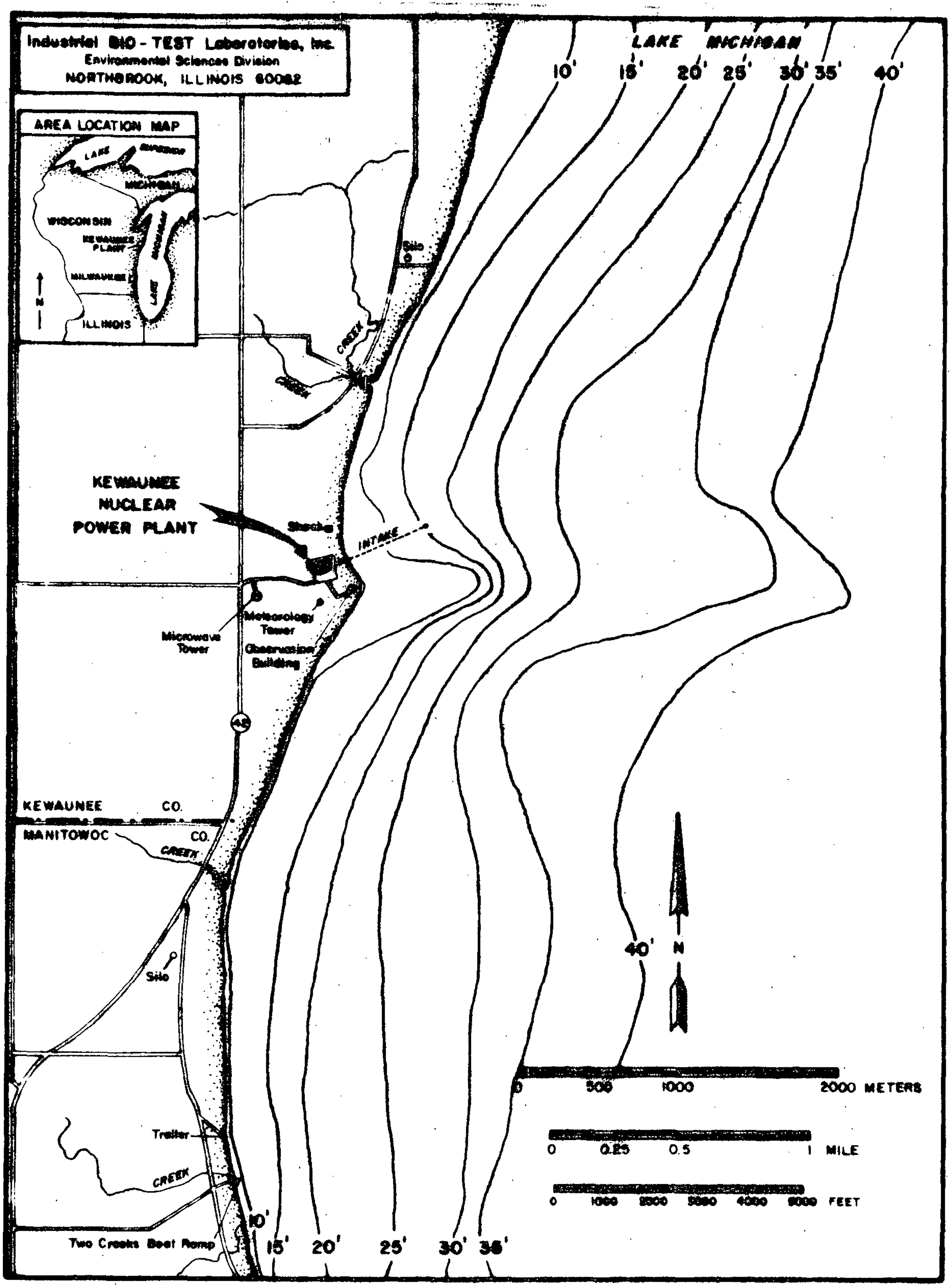

Figure 13.6. Nearshore bathymetry of Lake Michigan near the Kewaunee Nuclear Power Plant showing the submerged promontory just south of and adjacent to the site.

The proposed effect of the promontory upon the thermal plume is not an explicit part of the model. Furthermore, special application of the model has not been successful in defining the extent to which the thermal plume and ambient water will be affected. A field program designed to verify the present model should present opportunities for refinement and extension of its capabilities to include the special case of the submerged promontory.

C. Point Beach Influence

Evidence, based on infrared aerial photographs of the Point Beach thermal plume, suggests a possible interaction of this plume with the plume from KNPP located 4.2 miles north (Atomic Energy Commission 1972). In addition, application of the thermal plume model to Point Beach based on input data supplied by ANL (Paddock and Policastro 1972) also suggests an interaction since the 1F excess termperature isotherm extends past the KNPP site (Table 19). In this case, the KNPP plume would discharge into an area increased in ambient temperature 1F to 2F by the Point Beach plume.

The possible effect of the Point Beach plume on the KNPP plume has been modeled by increasing T_a at KNPP by 1.8F. The computations are based on summer conditions and results are presented in Table 4. From a comparison of Table 5, for conditions without the influence of the Point Beach plume, with Table 4, it is evident that the area within an excess temperature isotherm is slightly decreased by the Point Beach influence because the initial densimetric Froude number increases. However, the area enclosed by water at a given temperature may be greatly increased. For example, the 3F excess temperature isotherm without Point Beach influence is also the 58F water temperature isotherm, and it has an area of 191.4 acres. If ambient temperature is now increased by 1.8F due to the Point Beach plume, the 58F isotherm is the 1.2F excess temperature isotherm, and it has an area of 1242 acres.

The influence of the Point Beach plume will probably be a transient phemomenon as it moves in and out of the KNPP plume area.

D. Seasonal and Spatial Temperature Variations

The effect of seasonal changes in ambient temperature on the predicted characteristics of the thermal plume are presented in Tables 5 through 8. The ambient temperature chosen for each season is based on field data collected by BIO-TEST from April to December 1973. In each case the intake temperature and ambient temperature are chosen to be equal.

As the ambient temperature increases from spring to summer, the densimetric Froude number decreases. There is a corresponding increase in the area of an isotherm. For example, the 3F isotherm increases from 153 acres in the spring to 191 acres in the summer. Spring and fall conditions are similar.

During the winter, the discharge rate is lowered from 918 cfs to 655 cfs and ΔT increased from 20F to 28F. For ambient temperatures above 39.2F, the reduced discharge rate and increased ΔT result in a decrease in the Froude number. However, the winter ambient temperature is less than the temperature of maximum density of water (39.2F) and this may actually contribute to an increase in the Froude number. This is attributed to the fact that the density difference between water at a temperature several degrees less than and water at a temperature several degrees greater than 39.2F may be very small. This relationship is illustrated in Figure 13.7.

The two cases presented for winter in Tables 7 and 8 illustrate the above effect. The Froude numbers for these two cases are approximately equal to the Froude number for summer even though there has been a decrease in the discharge velocity and an increase in the discharge temperature. In the winter, a given excess temperature isotherm encloses a larger area than in the summer because ΔT is larger in the winter. For example, the size of the 10F excess temperature isotherm is approximately 11 acres in winter and 2 acres in summer.

The KNPP model requires a single ambient temperature input. It cannot explicitly treat the effect of horizontal temperature variations. Thus, horizontal temperature variations must be reduced to a single "ambient temperature" either by averaging or judicious choice. Vertical temperature variations, however, can be treated to the extent that the intake temperature can be specified independently of the ambient temperature. The situation in which these are different is most likely to occur in the summer when the water column becomes vertically stratified.

In fall, winter, and early spring the ambient water is isothermal. In late spring, there is a slight stratification up to 4F (cf. Chapter 1, June 1973 data) and in summer the vertical temperature variation can be as much as 15F (Atomic Energy Commission 1973). However, monthly temperature profiles presented in Chapter 1 of this report have shown at most an 8F stratification

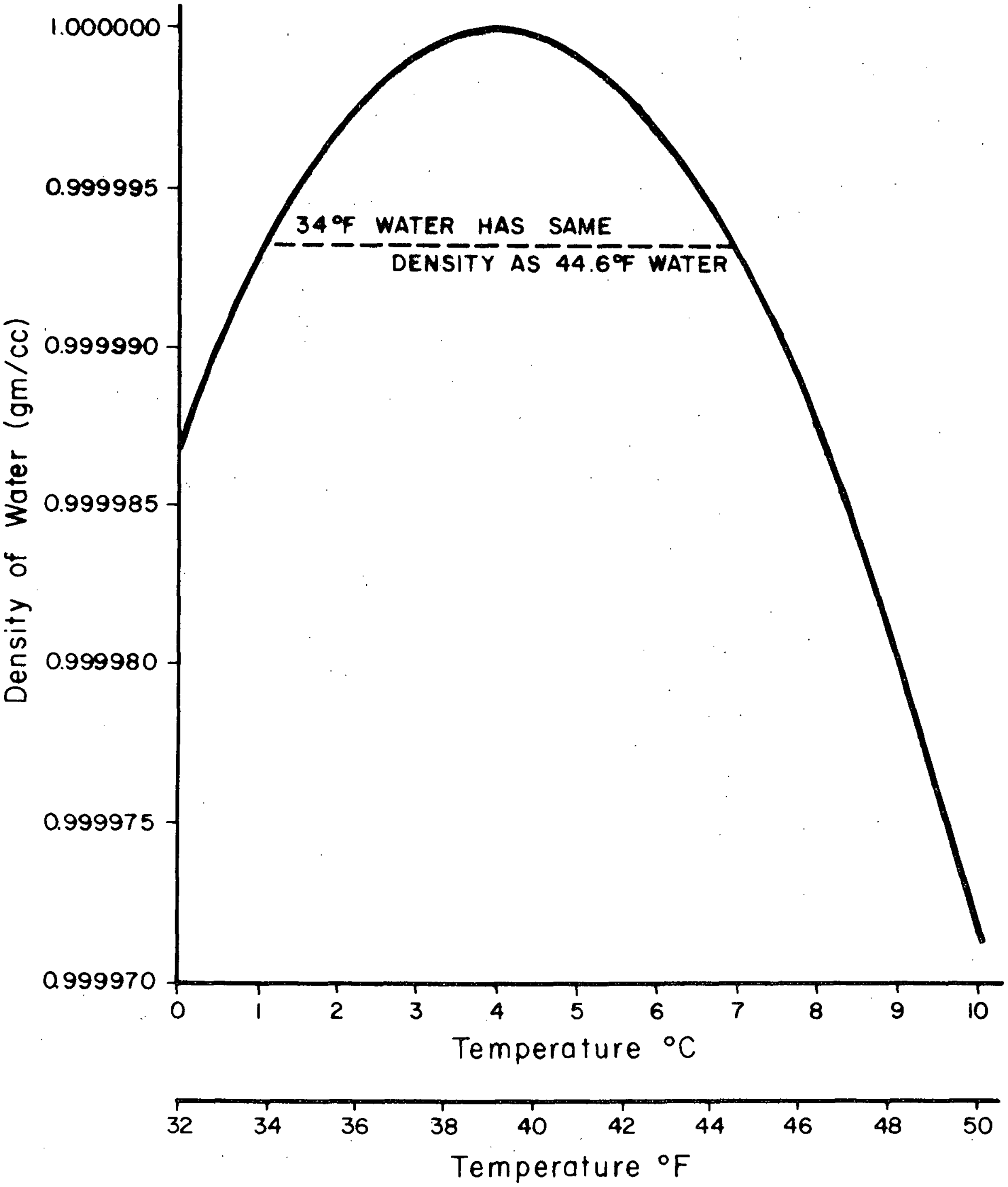

Figure 13.7. Density of pure water at one atmosphere pressure as a function of temperature.

in the vicinity of the intake.

Considering thermal stratification, the reduction of the plume size can be significant due to the intake structure being located in deeper cooler waters. Model predictions for a 4F and 8F temperature difference between intake and ambient are presented in Tables 9 and 10. For a given ΔT at the condensers (20F in this case), a decrease in T_i with respect to T_a means a decrease in the initial excess temperature at the discharge. This results in an increased Froude number. The effect of reducing T_i more than compensates for the fact that the plume is depth limited over a greater distance for increased F_o.

E. Ambient Currents and Winds

Ambient current (U_a) is a constant input parameter to the KNPP model. The extent of its influence on the thermal plume is determined by the ratio $R=U_o/U_a$. The model cannot explicitly predict the influence of current shear or of offshore/onshore directed currents. The currents are assumed to be spatially homogeneous and directed parallel to shore.

For a shallow water jet discharge bent parallel to the shore by a longshore ambient current, part of the excess momentum of the jet is lost to balance the pressure gradient across the jet. This pressure gradient results from a deceleration of the ambient flow on the offshore side of the jet and an eddy on the inshore side of the jet (Motz and Benedict 1971). In addition, the supply of diluting water on the inshore side of the jet is reduced. Both of these factors contribute to increasing the size of the plume. However, a stronger ambient current flow may actually decrease the size of a plume compared to a weaker flow. In this case, the larger volume rate of flow supplies enough water for entrainment and dilution to mitigate the adverse effects of bending (Pritchard 1973).

The effect of ambient currents is presented in Tables 11 through 13. These cases illustrate the influence of ambient currents during isothermal and vertically stratified conditions. For example, the increase from zero ambient current ($U_a=0$) and zero wind speed ($W=0$) (Table 5) to $U_a=0.25$ fps and $W=12$ mph significantly increases the size of the 3F excess temperature isotherm from 191 acres to 1206 acres. However, increasing U_a from 0.25 fps to 0.40 fps and W from 12 mph to 20 mph slightly decreases this area to 1088 acres due to the factors discussed above. In the case of low wind and strong stratification (Table 13), the area of the 3F excess temperature isotherm is reduced to 165 acres.

The wind and current speeds used are based on field data collected by BIO-TEST at KNPP in 1973 and reported in Chapter 1. It is apparent that ambient current is a significant factor in influencing plume size.

F. Sinking Plume

A sinking plume will occur during winter conditions when the ambient water temperature is less than the temperature of maximum density (39.2F). The heated discharge mixes with the cold ambient water creating a water mass of density greater than either the ambient or the heated water. When the mixture has a temperature of 39.2F, it will tend to sink to the bottom of the lake.

There is very little experimental data available on sinking thermal plumes

(Hoglund and Spigarelli 1972; Pipes et al. 1973). For purposes of this study, the area of the surface extent of the plume will be defined by the 39.2F isotherm.

The thermal plume predictions for winter conditions are presented in Tables 7 and 8. As the ambient water gets colder, the surface area of the plume decreases. For the case when T_a=37F, the 39.2F isotherm occurs at the 2.2F excess temperature isotherm. This isotherm has a centerline distance of 10,990 ft, a maximum width of 4056 ft, and a surface area of 899 acres. (These values were interpolated from Tables 7 and 8.) As T_a decreases to 34F, the 39.2F isotherm occurs at 5.2F excess temperature with a width of 1461 ft and a surface area of 125 acres. Field data (Pipes et al. 1973) indicate that the bottom temperatures within the area enclosed by the 39.2F isotherm are approximately equal to the surface temperature. Thus the $H_{1/2}$ predicted by the model is probably not applicable in this case.

At the 39.2F isotherm, the plume tends to sink to the bottom of the lake because it is more dense than the ambient water. In this region, bottom areas affected by excess temperature can be estimated based on cooling by dilution only. A surface cooling correction would not be appropriate since the thermal plume is on the lake bottom. For the cases where T_a=37F and T_a=34F, the area of the bottom which might be affected by excess temperatures between 1F and 2F is predicted to be 3173 acres and 3595 acres respectively. When the plume changes direction, these regions of excess temperature will be dissipated by currents and natural mixing (Pipes et al. 1973).

G. Changing Plant Operating Conditions

Changing the Plant's cooling water discharge rate (Q) or the temperature rise (ΔT) through the condensers is equivalent to changing the power output of the Plant. If the Plant is run at reduced power, ΔT will most likely be reduced. Tables 14, 15 and 16 give predictions for 100%, 80%, and 50% power respectively. The Froude number increases as the power output decreases with other conditions remaining constant, and the plume size is reduced. However, the plume size is not necessarily reduced by the same percentage as the power output. For example, for a 20% reduction in power output from 100% to 80%, the 3F excess temperature isotherm is reduced approximately 52% from 191.4 acres to 100.4 acres.

If the Q is reduced by 80% with ΔT=20F, the Froude number is decreased, and the plume size increases (Table 17).

H. Recirculation

Recirculation occurs when water from the heated discharge is drawn into the intake. This is most likely to occur when the plume passes over the intake. The possibility of this occurring can be assessed by comparing the predicted critical depth of the plume with the depth (15 ft) of the intake structure at 1600 ft offshore.

For summer conditions, the excess surface temperature at 1600 ft offshore is predicted to be about 6.5F (Table 6). At the critical depth ($H_{1/2}$=12ft), the excess temperature would be 3.25F. With an increase in T_i to 2.5F, to account for the greater depth of the intake (16 ft vs. 12 ft), the results are as presented in Table 18. Thus, for a 4.5% increase in T_i, the area enclosed by the 3F excess temperature isotherm increases 42% over the area without recirculation.

The recirculation temperature could be higher in cases with higher Froude numbers. The higher recirculation temperature results from an increased critical depth, and the fact that the plume is depth limited for a greater distance.

IV. Summary and Conclusions

The following conclusions are based upon an application of the KNPP thermal plume model to various Plant operating and environmental conditions:

1. The significant predictions of the model include:

a. The bottom slope at the KNPP site of 1/100 will result in a depth limited plume.

b. The influence of the Point Beach plume on the KNPP plume will be to decrease slightly the areas within isotherms of excess temperature, but to increase the areas within water temperature isotherms.

c. Seasonal temperature variations will influence the surface area of the thermal plume with an increase in size from spring to summer and a decrease from summer to fall. The size may increase again from fall to early winter, decreasing again in late winter during minimum lake temperatures.

d. Summer thermal stratification will be a significant factor in reducing the surface area of the thermal plume.

e. Ambient currents will be a significant factor in increasing the surface area of the thermal plume.

f. A sinking thermal plume will occur during the winter. The surface area will decrease from early to late winter. The area of the bottom affected by excess temperatures will increase from early to late winter.

g. A reduction in Plant power will reduce the surface area of the thermal plume.

h. Recirculation will probably occur under conditions of zero or low ambient current.

2. The predicted areas within isotherms are probably optimistic within a distance of 30 discharge widths (1200 ft) from the discharge structure and conservative thereafter.

3. If an eddy is generated by a northward current flowing past the submerged promontory, the ambient temperature will probably be locally increased due to reduced exchange with ambient water. However, the extent to which the KNPP thermal plume will be affected by this eddy has not been successfully modeled.

4. A field program of thermal plume measurements in the vicinity of the KNPP site will be necessary to verify the predictions of the model. Such a program should at least define the surface area, critical depth, velocity decay, and trajectory of the plume along with the environmental and Plant operating conditions. In addition, an estimate of the relative contribution of dilution and surface cooling to reducing the plume size should be obtained. A field program to study a sinking thermal plume should also be conducted.

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REPORT TO

WISCONSIN PUBLIC SERVICE CORPORATION
GREEN BAY, WISCONSIN

OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM OF LAKE MICHIGAN NEAR THE KEWAUNEE NUCLEAR POWER PLANT

JANUARY-DECEMBER 1976
PROJECT NO. 550107669

SIXTH ANNUAL REPORT

PREPARED AND SUBMITTED
BY
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March 1, 1977

PREFACE

The five previous annual reports prepared by NALCO Environmental Sciences (formerly Industrial BIO-TEST Laboratories, Inc.) documented the preoperational and first two years operational environmental conditions in Lake Michigan near the Kewaunee Nuclear Power Plant. The Sixth Annual Report contains environmental data collected during the third year of Plant operation. All phases of study are reported herein with an associated Appendix.

The operational studies presented in this report are responsive to the Technical Specifications for the Kewaunee Nuclear Power Plant, Appendix B-Environmental Technical Specifications, as approved by the U.S. Nuclear Regulatory Commission. The 1973 preoperational, and 1974 and 1975 operational studies were also responsive to the Technical Specifications, thus providing continuity between periods prior to and subsequent to Plant start-up with emphasis on the thermal and entrainment-impingement impact of Plant operation.

In addition to fulfilling the requirements of the U.S. Nuclear Regulatory Commission, Wisconsin Public Service Corporation has been responsive to the U.S. Environmental Protection Agency and the Wisconsin Department of Natural Resources who have jurisdiction under Public Law 92-500 and Chapter 147 Wisconsin Statutes, respectively. In Section 316(a) of Public Law 92-500, the owners of steam electric generating facilities are provided an opportunity to demonstrate that the "no discharge of heat" standard of performance requirement is more stringent than necessary to ensure the protection and propagation of a balanced, indigenous community of shellfish, fish and wildlife on the body of the water into which the discharge is made. At the request of the Wisconsin Public Service Corporation, NALCO Environmental Sciences has prepared a separate 316(a) Type 1 Demonstration Document for the Kewaunee Nuclear Power Plant. The demonstration document contains an evaluation of pre-operational (January 1971-May 1974) and operational (June 1974-July 1975) data from physical, chemical and biological studies conducted in Lake Michigan near the Plant. The results of this evaluation of thermal impact find that the operation of Kewaunee Nuclear Power Plant, with once-through cooling, has not caused appreciable harm to the balanced, indigenous community of shell-fish, fish and wildlife in Lake Michigan near the Plant. These conclusions were presented to the State of Wisconsin in a formal adjudicatory hearing on 10 August 1976 and the State of Wisconsin issued a Finding of Fact on 13 September 1976 which stated in part "...that no appreciable harm has resulted from the thermal component of the discharge, taking into account the interaction of such component with other pollutants and the additive effect of other thermal discharges, to a balanced, indigenous community of shellfish, fish and wildlife in and on the receiving water of Lake Michigan."

The data contained in this Annual Report support the conclusions established in the 316(a) Demonstration Document.

ACKNOWLEDGEMENTS

NALCO Environmental Sciences acknowledges and appreciates the technical assistance contributed by the following members of its consulting staff:

Mr. J. K. Hiltunen Benthos	Great Lakes Fisheries Laboratory
Ms. M. K. Romeo Programmer/Analyst	Private Consultant
Mr. R. Stemberger Rotifer Taxonomy	University of Michigan
Dr. R. G. Wetzel Algal Physiology	Michigan State University

The overall coordination of the study program was the responsibility of Dr. B. J. Cox, Project Coordinator. The direction of environmental and ecological studies was the responsibility of Mr. L. J. LaJeone, Associate Biologist, Fisheries Section.

The following NALCO ES personnel provided technical and supervisory assistance to the authors of specific chapters of this report:

Dr. H. Wang	Physical Sciences
Dr. J. C. Drozd	Water Chemistry
Mr. R. L. Weitzel	Aquatic Ecology
Mr. B. I. Muench	Fisheries
Dr. J. E. Hawley	Environmental Physiology
Dr. F. E. deLibero	Special Services

Appreciation is expressed to P. Parshall and N. Gara for their cartographic work and to F. Ochsner and staff for manuscript preparation.

The assistance provided by Mr. Thomas P. Meinz and Mr. Edward N. Newman of Wisconsin Public Service Corporation during the course of these studies has also been greatly appreciated.

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GENERAL INTRODUCTION AND SUMMARY

Larry J. JaJeone

OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR
KEWAUNEE NUCLEAR POWER PLANT

SIXTH ANNUAL REPORT
January - December 1976

GENERAL INTRODUCTION AND SUMMARY

Larry J. LaJeone

I. Introduction

This report covers the third year of operational environmental monitoring conducted during 1976, continuing the thermal impact studies to document the physical, chemical and biological conditions of Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant near Kewaunee, Wisconsin. These studies are responsive to the Technical Specifications for the Kewaunee Nuclear Power Plant, Appendix B-Environmental Technical Specifications, as approved by the U.S. Nuclear Regulatory Commission.

The Kewaunee Nuclear Power Plant is located on the west shore of Lake Michigan, approximately 8 miles south of Kewaunee, 27 miles southeast of Green Bay and 90 miles north of Milwaukee. The facility employs a single pressurized water reactor (PWR) nuclear generating unit and produces a rated net output of 540 megawatts electric (MWe). The unit began operation in June 1974.

Lake Michigan water is circulated in a once-through cooling system which has a shoreline discharge. The cooling water intake structure is located approximately 1,600 feet offshore at a depth of 16 feet. Condenser cooling water is drawn from Lake Michigan at a rate of 287,000 gallons per minute (gpm) during winter and 413,000 gpm during summer. The maximum rise in cooling water temperature is 15.5 C (28 F) and 11.1 C (20 F) above intake temperature for winter and summer, respectively. Cooling water is discharged into an outlet basin at the shoreline through a pipe located just below the lake surface.

The 1976 operational monitoring studies were based on a total of 33 sampling locations and three current meter moorings in the vicinity of the Kewaunee Nuclear Power Plant (Figure 1; Table 1). Lake sampling was conducted along five eastwest transects. A central transect was situated directly offshore from the mouth of the discharge. There were two transects on each side of and running parallel to the central transect: one approximately one-half statute mile and the other approximately two statute miles from the central transect. The sampling locations were positioned along each transect on the basis of the distance from the discharge and the water depth. Sampling points were found using ship-board radar and electronic depth sounding instrumentation.

The frequency of sampling and locations for each category are presented in Table 1. Lake currents and temperature were monitored continuously from April through November. Water quality, bacteriology, water column profiles, phytoplankton, zooplankton, entrainment and fish (gill nets and shoreline seining) were sampled monthly, April through November. Drogue tracking was conducted concurrently with water quality sampling. Benthos and periphyton, were sampled in May, July, September and November. Fish eggs and larvae were sampled in April, May, July, September and November. General descriptive field data collected at each sampling location included wind direction and speed, air temperature (wet and dry bulb), percent cloud cover, water color, Secchi disc reading and time of day.

The results of the 1976 studies are reported under technical

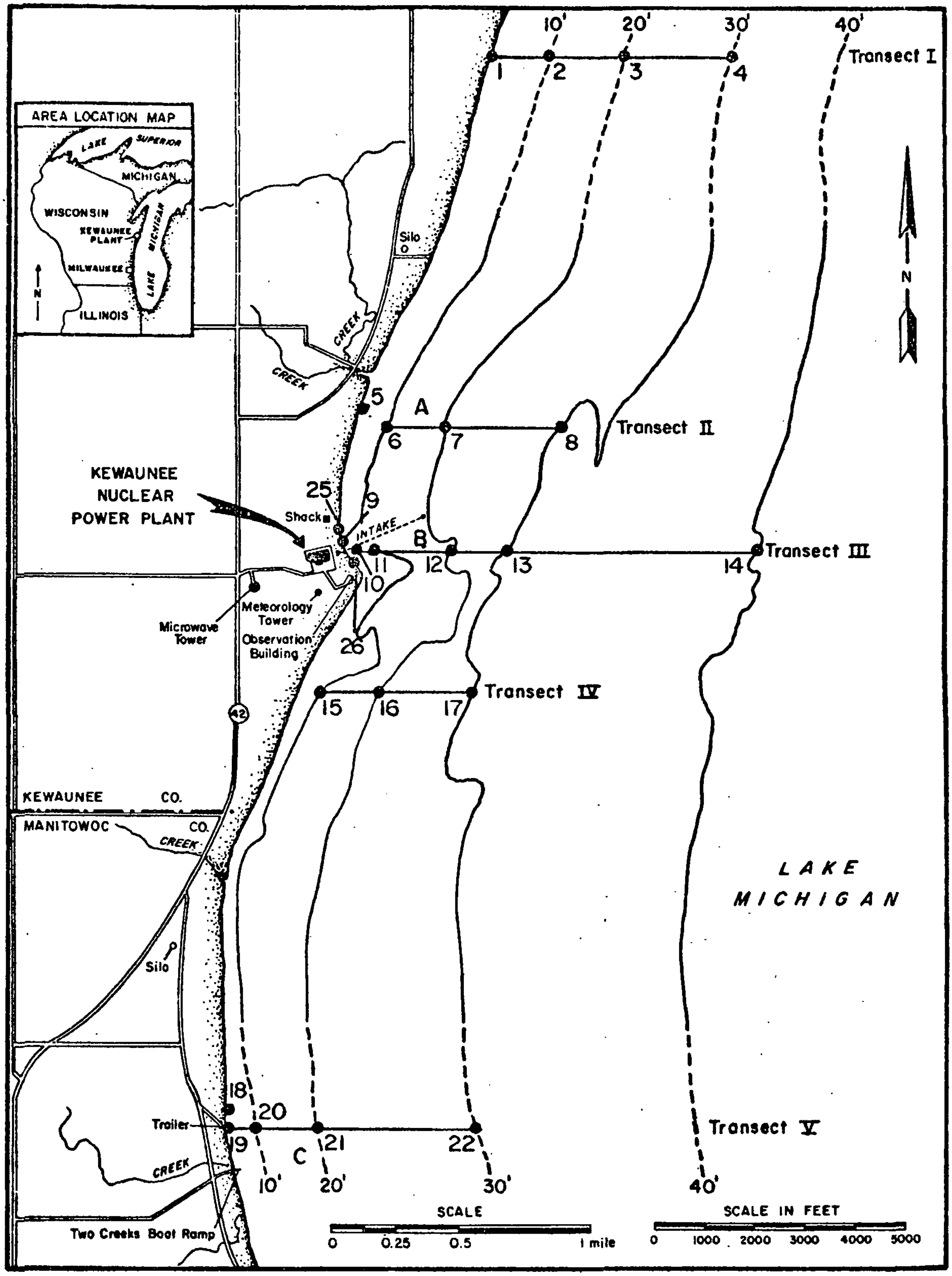

Figure 1. Sampling locations used in the environmental monitoring program of Lake Michigan near the Kewaunee Nuclear Power Plant during 1976.

Table 1. Field schedule and sampling locations for the environmental monitoring program of Lake Michigan near the Kewaunee Nuclear Power Plant during 1976.

Category	Sampling Period Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sampling Locations[a]
Physical[b]													
Currents and temperatures	-	-	-	X	X	X	X	X	X	X	X	-	three permanent moorings (chapter 1)
Wind	-	-	-	-	-	X	X	X	X	X	X	-	one permanent meteorological station
Drogue study	-	-	-	X	X	X	X	X	X	X	X	-	
Shoreline erosion	-	-	X	-	-	X	-	-	-	-	-	-	
Chemistry													
Profiles	-	-	-	X	X	X	X	X	X	X	X	-	2-4, 6-8, 10-14, 15-17, 20-22
Water quality	-	-	-	X	X	X	X	X	X	X	X	-	2, 7, 11, 12, 14, 16, 20
Bacteriology	-	-	-	X	X	X	X	X	X	X	X	-	2, 7, 11, 12, 14, 16, 20
Biology													
Phytoplankton	-	-	-	X	X	X	X	X	X	X	X	-	2, 7, 11, 12, 14, 16, 20
Zooplankton	-	-	-	X	X	X	X	X	X	X	X	-	2-4, 6-8, 11-13, 15-17, 20-22
Periphyton	-	-	-	-	X	-	X	-	X	-	X	-	1, 9, 18, 25, 26
Benthos	-	-	-	-	X	-	X	-	X	-	X	-	3, 6-8, 11-13, 16, 17
Entrainment													
Phytoplankton physiology	X	X	-	X	X	X	X	X	X	X	X	-	E-0 through E-5
Zooplankton physiology	X	X	-	X	X	X	X	X	X	X	X	-	E-0 through E-5
Fisheries													
Minnow seining	-	-	-	X	X	X	X	X	X	X	X	-	5, 9, 19
Gill netting	-	-	-	X	X	X	X	X	X	X	X	-	A, B, C
Fish eggs and larvae	-	-	-	X	X	-	X	-	X	-	X	-	6, 7, 11, 12, 20, 21

[a] Locations 23 and 24, along 40 ft depth contour, deleted from 1976 study.
[b] Currents, temperatures and wind monitored continuously.

titles in individual chapters of this report. The specific objectives of each individual study are covered in detail in the respective chapters, together with a presentation of results and conclusions. All numerical data collected or developed are presented in the Appendix.

II. Summary

The data collected as part of these 1976 studies, together with those from five previous programs in 1971, 1972, 1973, 1974, and 197 provide a detailed description of preoperational and operational conditions in the vicinity of the Kewaunee Nuclear Power Plant. The 1971 through 1973 information was used as the data base to which the 1974 through 1976 operational data were compared in an effort to determine the effects of the thermal discharge on the aquatic environment.

The following points provide a summary of studies conducted to date:

1. Third year operational conditions in the aquatic environment near the Kewaunee Nuclear Power Plant have been described;

2. Operational data from 1976 which can be compared with previous operational and preoperational data have been developed;

3. Operational data from 1976 have been compared with 1974 and 1975 operational data and preoperational baseline data; and

4. No unusually sensitive environmental or ecological area has been identified that would warrant modification of present plans of the Wisconsin Public Service Corporation for operation of the Kewaunee Nuclear Power Plant which is in agreement with the findings of the State of Wisconsin.

The summary and conclusions from each of the 1976 studies reported under individual technical titles in chapters of this report follow:

Chapter 1: Nearshore Currents, Temperature and Wind

1. The data collected describe the spatial and temporal shore water circulation and temperature structure, and the wind distribution in the vicinity of KNPP for the April-November 1976 measurement period.

2. The water mass movement in the area of KNPP is spatially homogeneous. The current speed and direction are influenced by the bottom topography and the prevailing local winds.

3. The net water displacement past the KNPP was generally shore-parallel toward the northeast. Average monthly current speeds range between 0.16 ft/sec and 0.34 ft/sec. The maximum current speed recorded was 0.99 ft/sec.

4. The greatest persistence of current in a single direction was 38 hours toward the SSW and the greatest persistence of current speed was 37 hours for speeds within the 0.10-0.25 ft/sec class.

5. Periods of greatest monthly temperature range occurred during July and August 1976. This range was found to be as great as 12.7 C.

6. A maximum temperature of 20.5 C was recorded during August 1976 at the Offshore Station and a minimum temperature of 1.8 C was recorded during November 1976 at the North Station.

7. Net wind displacement past the KNPP was generally toward the northeast. Average monthly wind speeds ranged from 14.8 to 19.4 ft/sec. The maximum wind speed recorded was 54.1 ft/sec.

8. The greatest persistence of wind in a single direction was 18 hours from the NNW and the greatest persistence of wind speed was 22 hours for speeds between 12-19 ft/sec.

Chapter 2: Water Chemistry & Bacteriology

1. Water quality in Lake Michigan near the Kewaunee Nuclear Power Plant was in compliance with the standards established by the Wisconsin Department of Natural Resources.

2. Elevated temperatures due to the discharge of KNPP were measured every month of the study period but April and May. These temperature increases were limited to the upper portion of the water column and to locations close to the immediate discharge area of KNPP.

3. Seasonal changes were noted for water temperature, dissolved oxygen, pH, and several nutrients.

4. A thermocline existed at many 30 and 40-ft contour locations in July and August. Increased dissolved oxygen concentrations and pH's occurred along the thermocline in conjunction with the regions of greatest temperature decrease with depth.

5. The concentrations of some of the aquatic nutrients were influenced by biological activity during the summer.

6. The major anions and cations measured displayed little variation.

7. Turbidities and nonfiltrable residues varied less during this study period than in several past years because less weather-related turbulence occurred near the sampling dates.

8. Fecal coliform bacteria densities and fecal streptococci densities were very low except in July, when fecal coliforms were high throughout the study area. The ratio of fecal coliform bacteria to fecal steptococci bacteria was representative of waste runoff from poultry and livestock, with the exception of July, when the ratio

was characteristic of human wastes.

9. Biochemical oxygen demand, chemical oxygen demand and total organic carbon values exhibited slight variations and indicated little or no organic pollution in Lake Michigan near KNPP.

10. Chlorine and hydrazine were not detected in Lake Michigan waters near KNPP during the 1976 study period.

11. Total iron and manganese concentrations decreased with distance from shore because of the reduced turbulence in deeper waters. The other trace metals, with the exception of a few mercury values, displayed only minor variations; the concentrations of many metals were near or below their analytical detection limits.

12. Comparison of spatial means indicated that Lake Michigan waters near KNPP were generally homogeneous. Statistical evaluation of data showed that few parameters were significantly different in front of the KNPP discharge from control areas along the same depth contour. The one difference which was observed was environmentally insignificant.

13. The differences in water quality between this study and previous studies were generally minor in comparison to the natural spatial and temporal variations found in Lake Michigan.

14. Operation of KNPP had no effect on the water quality of Lake Michigan with the exception of slightly elevated water temperature close to the Plant's discharge.

Chapter 3: Phytoplankton

1. Phytoplankton collected near Kewaunee Nuclear Power Plant included seven major algal divisions. The five most abundant

divisions in decreasing order were Bacillariophyta (diatoms), Cyanophyta (blue-green algae), Chrysophyta (golden-brown algae), Chlorophyta (green algae) and Cryptophyta. This same order of abundance was observed during the 1972-1973 preoperational periods and 1974-1975 operational periods of phytoplankton monitoring near KNPP.

2. There were some new taxa not reported in the previous monitoring programs which replaced some previously reported taxa. This replacement was confined to the rarer forms which were reported intermittently at all locations. The total number of taxa and the most abundant forms were similar to those reported in previous years.

3. Phytoplankton densities were generally larger in 1976 than densities of any other previous year. This increase reflected diatom densities and was not exclusively related to Plant operation since it occurred at both the discharge location and control locations in the inshore area.

4. The dominant species changed very little from 1971 to 1976. Diatoms were always the most abundant group and comprised the largest number of species. *Fragilaria crotonensis*, *F. pinnata*, and *Tabellaria flocculosa* continued to be the most abundant species throughout the entire study area.

5. Blue-green algae, primarily represented by *Coelosphaerium naegelianum*, were most abundant at all locations in September. Summer peak densities in 1976 were similar to the 1975 densities but lower than those in 1973 and 1974.

6. Golden-brown algal densities were lower than in 1975. There was a seasonal increase and decrease in their densities through the summer and fall. Dinobryon divergens and D. sociale were the most common species.

7. Green algae were represented by a relatively large number of taxa even though they were present in small number and never comprised more than 3% of the total phytoplankton.

8. Phytoplankton densities were usually significantly ($P \leq 0.05$) more abundant at the inshore locations than at the middle and offshore locations. This was also true for the division Bacillariophyta (diatoms) which exhibited the same distributional patterns during the previous studies near KNPP and was interpreted to be due to normal shoreline effect.

9. Differences in diatom densities at locations within and outside the influence of the thermal plume did not appear to be related to differences in water temperature.

The scouring of periphytic diatoms by discharge canal currents and their subsequent incorporation into the plankton was probably the primary cause of the usually higher diatom densities reported in the immediate discharge area. This pattern was also observed during the 1974 and 1975 operational periods.

Chapter 4: Zooplankton

1. Eighty-two zooplankton taxa were observed near KNPP, five of which had not been observed in the study area during previous studies. All of the newly sighted taxa were rarely encountered and

did not constitute a significant change in community structure from previous studies.

2. The zooplankton community expressed the yearly maximum in July and a secondary maximum in September.

3. Rotifera ranged from 60% to 91% of the zooplankton density and, therefore, trends among total zooplankton were usually a reflection of trends among Rotifera.

4. Three or less taxa always constituted 47% of the zooplankton mean density for each month. This dominance pattern was caused by five taxa: Keratella spp., Polyarthra spp., Synchaeta spp., Bosmina longirostris, and cyclopoid copepodites.

5. In a location by location survey in each month, one of the five major taxa was always dominant except for a unique situation at Locations 6, 11, and 12 in June. On that occasion the sub-dominant rotifer Ploesoma was the most numerous zooplankter.

6. The rotifers Chromogaster spp. and Ascomorpha spp., whose populations at Kewaunee have heretofore been miniscule, appeared in numbers greater than $200/m^3$ for two and three consecutive months, respectively.

7. Zooplankton were generally more dense near shore than at mid- and offshore locations throughout the study.

8. Rotifer populations expressed maxima or high plateaus in response to strong dominance by one of the three major genera.

9. The major copepod taxa were nauplii, calanoid copepodites, cyclopoid copepodites, Cyclops bicuspidatus thomasi, Diaptomus ashlandi, D. minutus, D. oregonensis, and Tropocyclops prasinus

mexicanus. The seasonal dynamics among the Copepoda were dominated by the immature forms.

10. The Copepoda expressed their yearly maximum in July, but were present in monthly mean densities greater than 10,000/m^3 from July through November.

11. The major cladoceran taxa were Bosmina longirostris, Daphnia retrocurva, Eubosmina coregoni, D. galeata mendotae. Seasonal dynamics among the Cladocera were dominated by Bosmina longirostris.

12. Cladoceran populations expressed a strong yearly maximum in September, but were very abundant July through October.

13. The cladoceran Chydorus gibbus, whose population at Kewaunee has heretofore been miniscule, appeared in numbers greater than 100/m^3 in July 1976.

14. Significant ($P \leq 0.05$) abundance trends were detected for the 30 ft contour during September and October, but Plant effect could not be defined as the cause.

Chapter 5: Phytoplankton Physiology

Immediate and delayed effects of plant and thermal plume entrainment were assessed at KNPP during 1976 on phytoplankton carbon fixation rates, chlorophyll *a* concentrations, abundance and species composition. Data analysis revealed the following:

1. The immediate impact of condenser passage on phytoplankton carbon fixation rates and chlorophyll *a* concentrations was considered minimal during 1976. Values for both parameters measured at the discharge were 6% (annual mean) lower than at the intake.

2. Phytoplankton abundance observed at the discharge was approximately 30% higher than at the intake at 7 hours after sample collection with no trends in species composition changes observed between the two locations.

3. Delayed effects of Plant entrainment were not evident for phytoplankton chlorophyll a concentrations and species composition during 1976 sampling periods. Carbon fixation rates and phytoplankton abundance measured from 24 through 72 hours after sample collection, however, exhibited some evidence of delayed reaction to Plant entrainment.

4. Phytoplankton subjected to thermal plume entrainment responded with increased carbon fixation rates, chlorophyll a concentrations and abundance relative to a Lake Michigan control location outside the influence of the thermal plume. Analyses conducted at 24, 48 and 72 hours after sample collection revealed no evidence of recovery toward ambient values for the three parameters mentioned.

5. The overall impact of KNPP on the physiology of the phytoplankton community near the Plant was an immediate general increase in productivity in the area of the thermal plume with some evidence of delayed reaction to entrainment between 24 and 72 hours after sample collection.

Chapter 6: Zooplankton Physiology

1. Entrained zooplankton (microcrustacea) population densities ranged from 160/m^3 in May to 70379/m^3 in September and averaged 13635/m^3 during 1976.

2. Copepoda were more abundant than Cladocera in all months

except July and September through November when B. longirostris comprised 63% of the zooplankton community.

3. The combined thermal and mechanical effects of condenser passage on zooplankton resulted in immotilities ranging from 1.4% to 14.4% and averaging 8.9%. Approximately 33% of the total zooplankton immotility was attributed to thermal effects.

4. Condenser mortality, four hours after entrainment, averaged 8.8% with no clear indication of delayed mortality or recovery from the immediate effects (0 hrs) of condenser passage.

5. Immotility following condenser passage was correlated directly with species size but was apparently unrelated to the presence or magnitude of the discharge water temperature, indicating that mechanical factors were primarily responsible for the observed effects.

6. Since zooplankton immotility and mortality did not appear to increase during plume entrainment, the effects of prolonged entrainment within the immediate discharge area was negligible.

Chapter 8: Benthic Macroinvertebrates

1. Two distinct substrate types were sampled near KNPP in 1976. Unstable, shifting sand substrates were prevalent at the 10 ft depth contour locations, and various sized rocks covered with varying amounts of Cladophora predominated at 20 and 30 ft depth contour locations.

2. Assemblages of oligochaetes and chironomids were the principal macroinvertebrates collected. Lesser numbers of nematodes, ostracodes, amphipods, gastropods and aquatic insects, other than midges, also occurred.

3. The total benthic community was subdivided into two broad overlapping communities which correlated with the substrate type. Principal components of the sand community of the 10 ft depth locations were the naidids _Piguetiella michiganensis_, _Unicinais uncinata_, and _Vejdovskyella intermedia_; the tubificids _Limnodrilus hoffmeisteri_ and _Potamothrix moldaviensis_; the chironomids _Dicrotendipes_ sp., _Paracladopelma_ sp., and _Thienemannimyia_ Series; and ostracods. Principal components of the 20 and 30 ft depth locations were the naidids _Nais_ sp., _Stylaria lacustris_, and _Vejdovskyella intermedia_; the tubificids _Potamothrix moldaviensis_, and _P. vejdovskyi_; the lumbriculid _Stylodrilus heringianus_; and the midges _Heterotrissocladius_ sp., _Microtendipes_ sp., and _Thienemannimyia_ Series.

4. Empirical comparisons of community structure and species diversity indices between locations inside (Location 11) and outside (Location 6) the Immediate Discharge Area indicated no evidence of effects on the macroinvertebrate community due to Plant operation.

5. Statistical comparisons of the abundance of predominant fauna between these locations further substantiated empirical evaluation.

6. Analysis of major taxa collected at Locations 6 and 11 from 1973 through 1976 indicated no long term permanent alterations in the benthic macroinvertebrate community due to Plant operation.

Chapter 9: Fish Population and Life History

1. No appreciable thermal influence of the discharge on fish sampling locations closest to the Kewaunee Nuclear Power Plant

(Locations B and 9) was detected. Increased water temperatures possibly due to the Plant's discharge were detected only on 17 November at Locations A and B.

2. Twenty-one species of fish and one hybrid were collected in Lake Michigan near the Plant in 1976, comprising a total catch of 5952 fish. Gill nets captured 4789 (80.5%) fish and shoreline seining accounted for 1163 (19.5%) fish.

3. Principal species collected within the study area were alewife, rainbow smelt, lake chub, lake trout, yellow perch, white sucker, longnose dace, slimy sculpin, brown trout, chinook salmon and longnose sucker. Additional species of sport or commercial value collected in the area were rainbow trout, coho salmon, brook trout, tiger trout, lake whitefish and round whitefish.

4. Seasonal abundance and spatial distribution were plotted for major species. Peak abundance of alewife, smelt, lake chub and lake trout in the study area appeared to coincide with spawning seasons while peak abundance of other major species did not coincide. With the exception of longnose sucker, no distinct patterns of spatial distribution within the study area were detected for principal species. However, intermittent tributaries and different habitats at seining locations did influence the distribution of some species.

5. Species collected in spawning condition within the area were alewife, smelt, lake chub, lake trout, rainbow trout, coho salmon, and yellow perch. Species believed to have spawned successfully in the vicinity of KNPP were alewife, smelt, lake chub, longnose dace and slimy sculpin.

6. Principal forage of larger, predatory species inhabiting the area consisted of alewife, smelt and slimy sculpin.

7. Data gathered from the recovery of tagged fish indicate that lake trout, brown trout and yellow perch travel considerable distances along the western shore of Lake Michigan, though extreme movements are exceptional. Recapture of several fish in close proximity to the point of release further indicates that there may be some pattern in their seasonal movements. Brown trout apparently remain in the vicinity of thermal effluents for some time during the colder months.

8. Comparison of data compiled over the last four years failed to depict any substantive changes in the fish population of the area attributable to Plant operation. Considerable variations in species composition, annual catches, seasonal abundance and spatial distribution of the fish community could not be related to operation of the Plant. Seasonal attraction of brown trout and carp to the discharge area were the only effects of Plant operations observed.

Chapter 10: Shoreline Erosion

1. The shoreline in the vicinity of the KNPP continues to be subjected to severe erosion and much of it continues in an unstabilized state. The principal cause appears to be continued high lake levels (above 579 ft,IGLD) and wave attack associated with storms and high winds.

2. Considerable differences in local rates of erosion are apparent within the stretch of shoreline where observations were made during this study.

3. No major changes were observed in shoreline configuration in 1976; minor earth slides reflected natural bank stabilizing processes.

4. No unusual or unexpected erosion was noted that could be attributed to the operation of the KNPP, either at the present time or by comparison with operational photographs taken earlier and with those taken during the preoperational period.

Chapter 1

NEARSHORE CURRENTS, TEMPERATURE AND WIND

Jeffrey E. Hilland

OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR
KEWAUNEE NUCLEAR POWER PLANT

SIXTH ANNUAL REPORT
January - December 1976

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Chapter 1

NEARSHORE CURRENTS, TEMPERATURE, AND WIND

Jeffrey E. Hilland

I. Introduction

During the months of April through November 1976 nearshore current, temperature, and wind conditions were monitored in the vicinity of the Kewaunee Nuclear Power Plant (KNPP) on Lake Michigan. Similar investigations of nearshore operational conditions were conducted and documented during the years of 1971 through 1975 (Industrial BIO-TEST Laboratories Inc. 1972, 1973, 1974 and 1975; NALCO Environmental Sciences 1976). The current, temperature, and meteorological data gathered during the period of April through November 1976 are presented in Appendix 1.

The specific objectives of the present investigation were:

1. to measure the lake currents in the vicinity of KNPP using moored current meters on a time-continuous basis, and current drogues on a periodic basis;
2. to describe the spatial and temporal nearshore water circulations in the vicinity of KNPP based upon the current measurements;
3. to measure the nearshore lake temperature using time-continuous temperature recorders;
4. to describe the temporal nearshore temperature structure in the vicinity of KNPP based on the temperature measurements;
5. to measure the wind speed and direction concurrently with the lake current and temperature measurements; and
6. to describe the temporal wind patterns in the vicinity of KNPP based on the wind measurements.

II. Field and Analytical Procedures

A. Current Measurements

1. Time-Continuous Current Meter Measurements

Current meter measurements were recorded at thirty-minute averages continuously from 28 April to 16 November 1976 at each of three mooring stations (Figure 1.1). An ENDECO Type 105 current meter was located at a depth of approximately 7 ft below the water surface at each station, using the mooring system shown in Figure 1.2. The current meters were serviced on a monthly basis which included replacing batteries, film and dessicant bags, and adjusting the instruments trim.

The Endeco Type 105 current meter is an axial flow, ducted impeller instrument specifically designed for use in the nearshore zone (Figure 1.3). The meter is capable of recording analog signals of impeller rotation and magnetic bearing of the instrument on 16 mm film. Each instrument was calibrated prior to field installation, in a flume, to determine threshold current speed and accuracy of the instrument. The calibrations were conducted by personnel at the Chesapeake Bay Institute of Johns Hopkins University. A threshold speed was determined for each current meter. The lowest threshold speed among the current meters was 0.07 ft/sec and the highest threshold speed was 0.10 ft/sec. The accuracy of speed measurement was determined to be within ±0.10 ft/sec of true speed. The accuracy of current direction was ±5 degrees at threshold speed, ±3.6 degrees above threshold speed, and is resolvable to ±1.0 degrees.

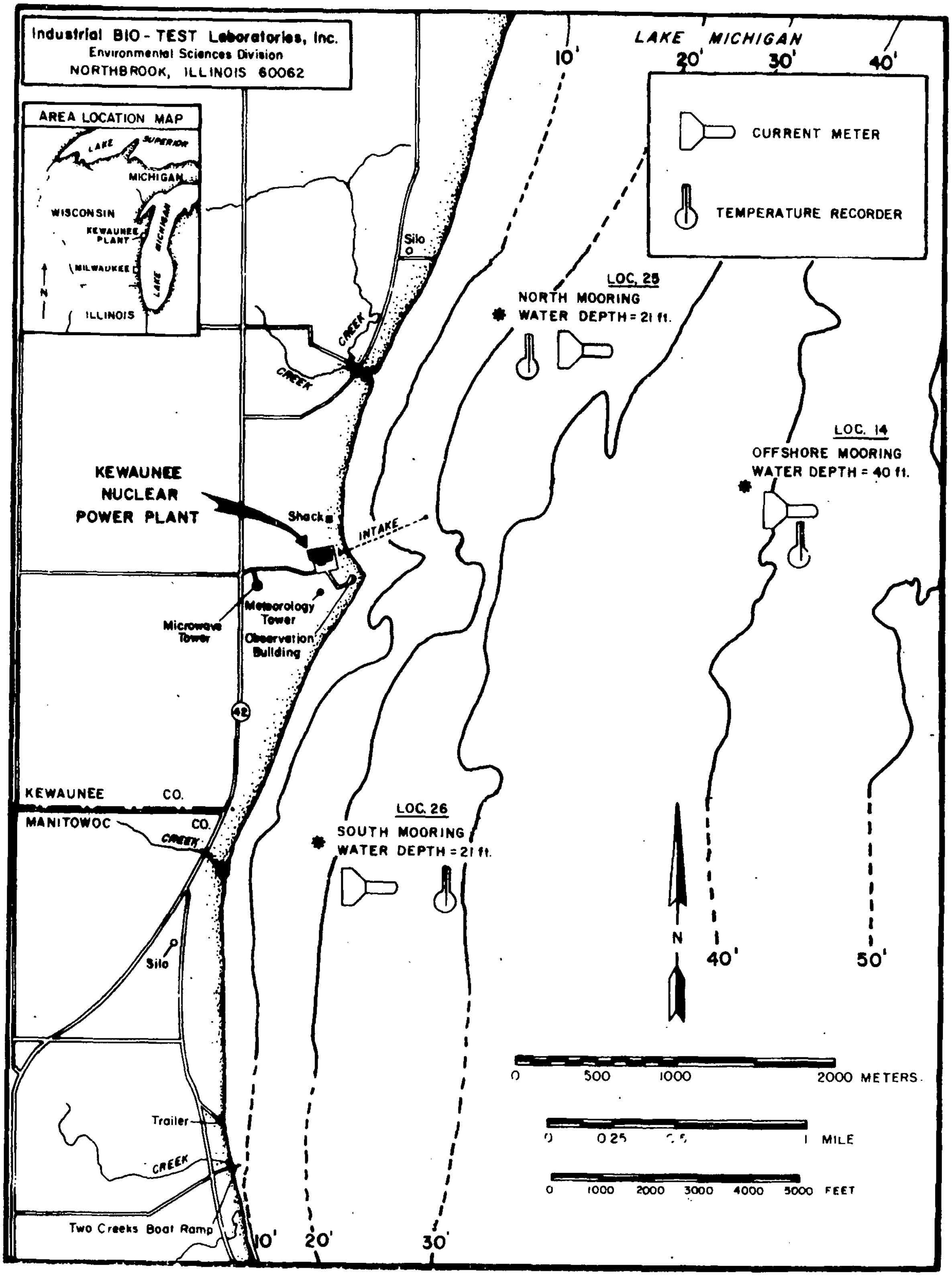


Figure 1.1. Current meter mooring locations in Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant during 1976.

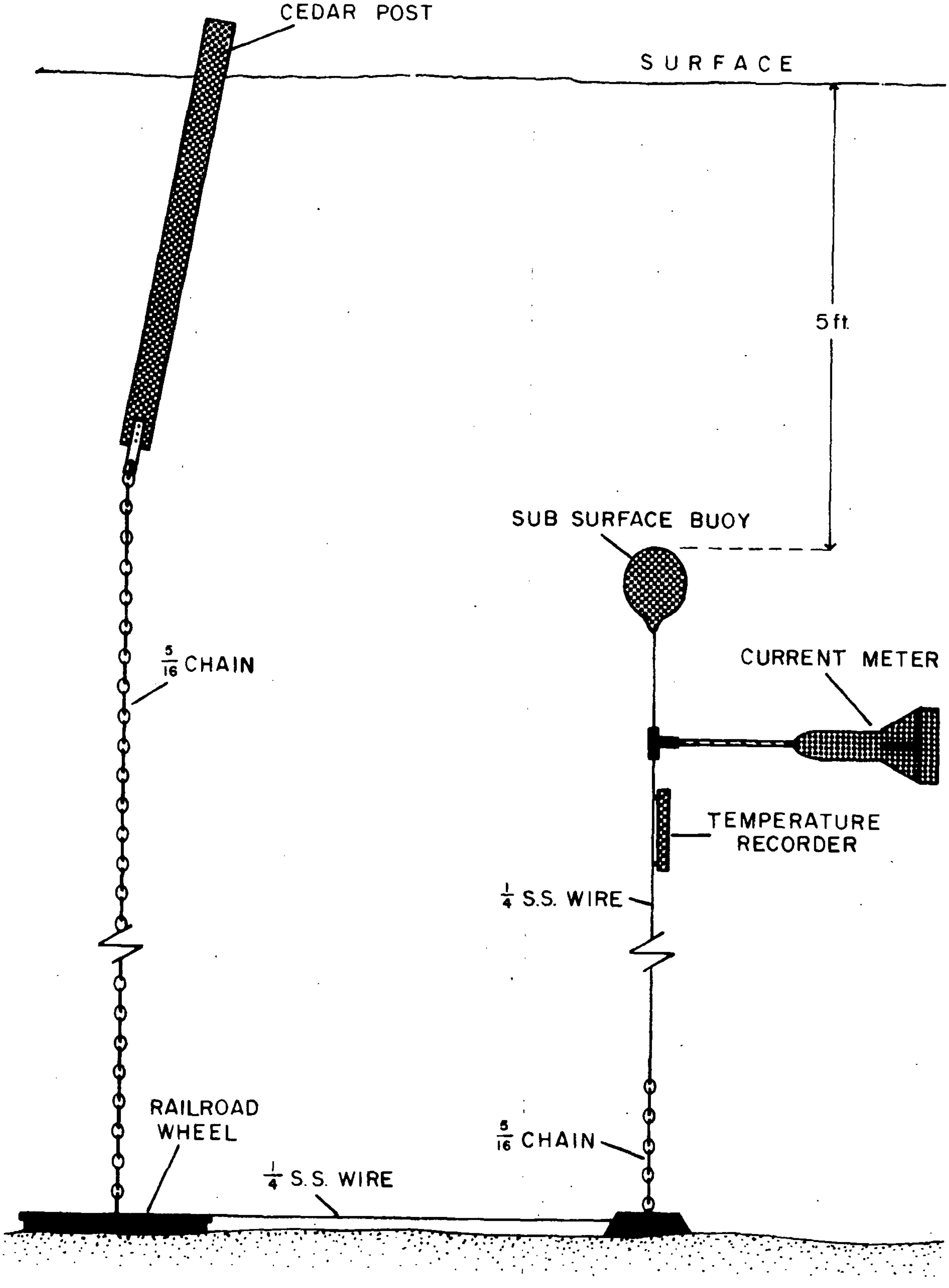


Figure 1.2. Current meter and temperature recorder mooring used in Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant during 1976.

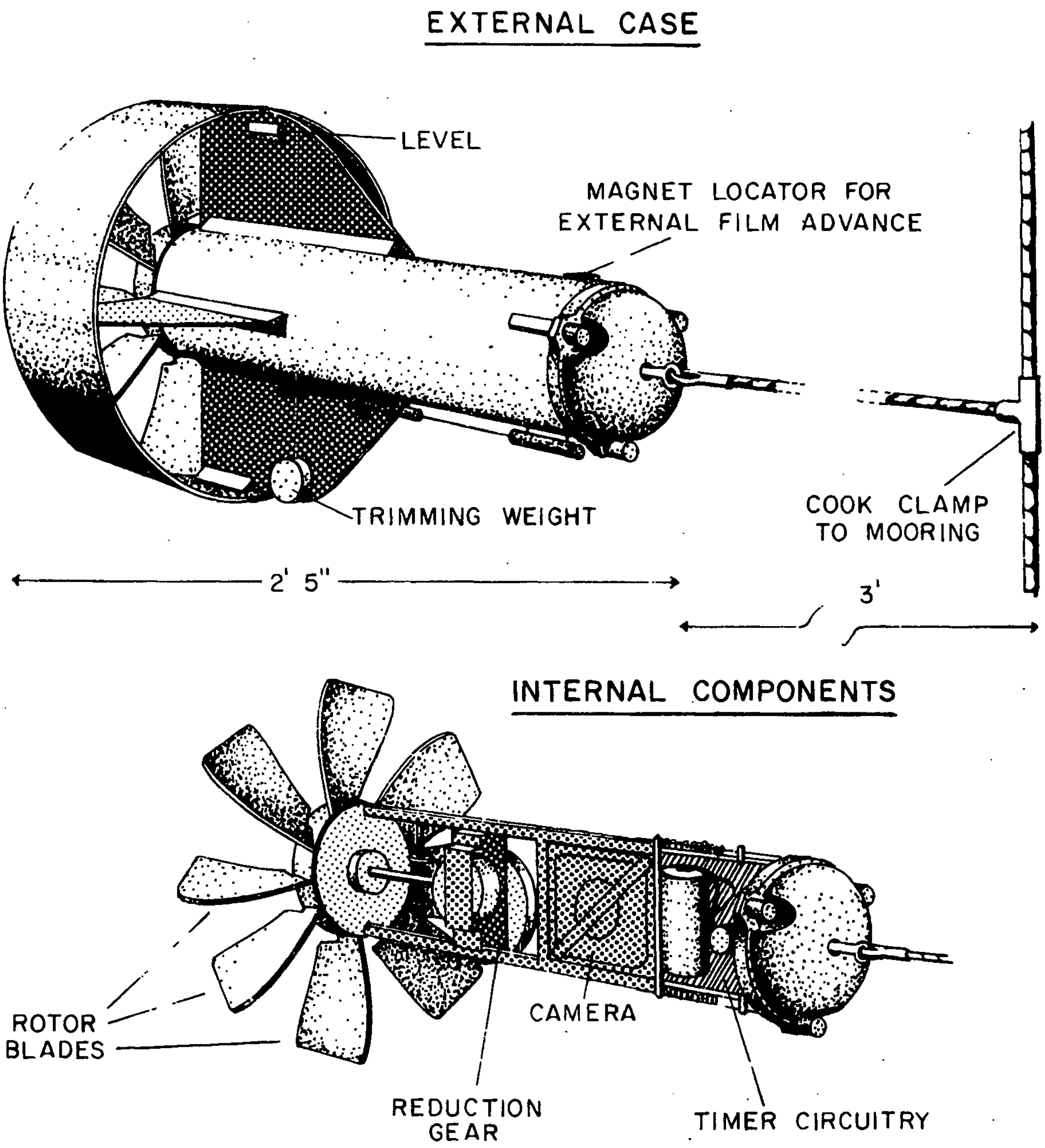


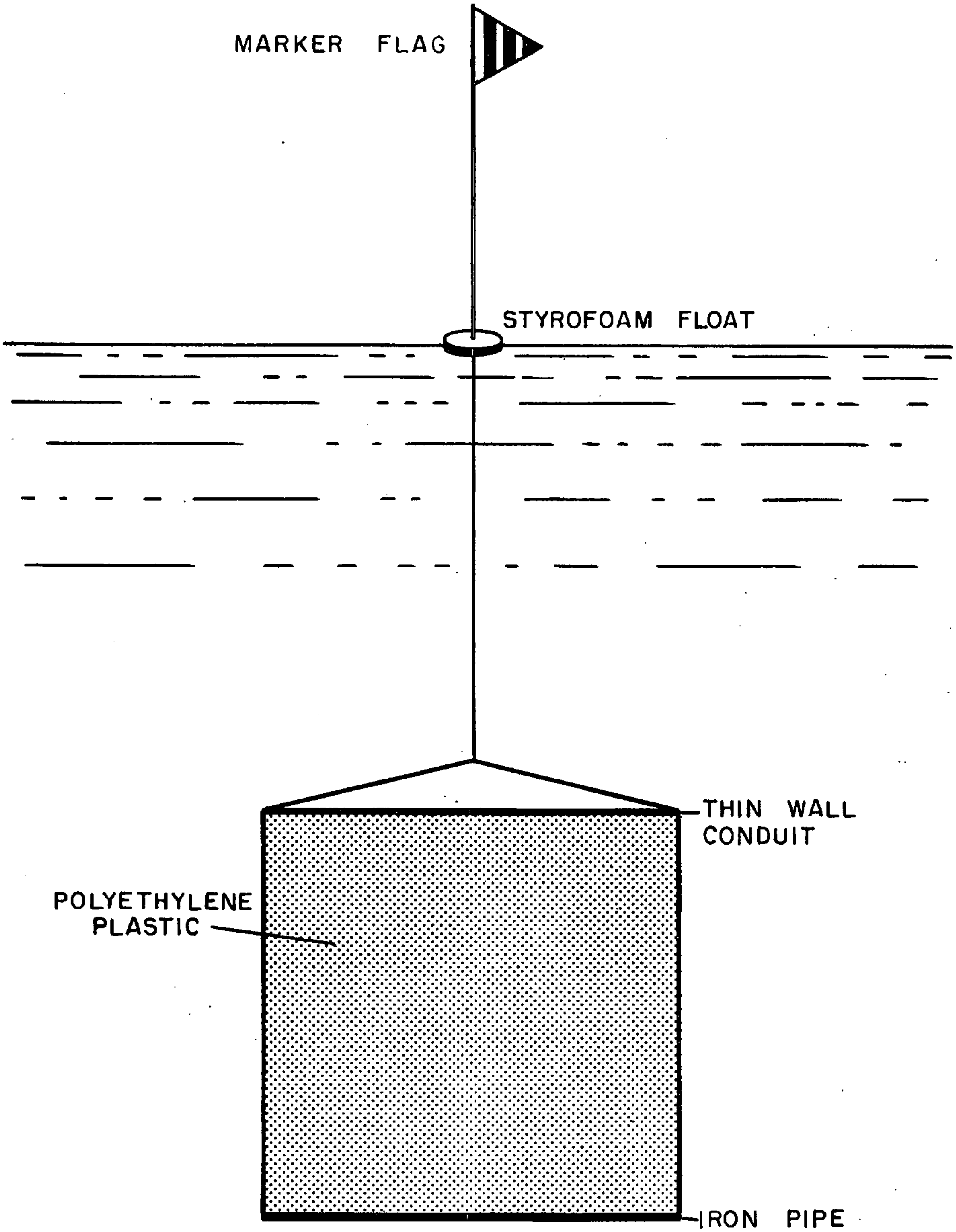
Figure 1.3. Recording current meter (ENDECO Type 105) used for time-continuous current recording in Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant during 1976.

Time series data of hourly vector averages of current speed and direction were used to construct plots of current speed and direction versus time, progressive vector diagrams (PROVECS), joint frequency tables of current speed and direction, and persistence tables of current speed and direction.

The PROVECS are constructed by connecting consecutive velocity vectors head to tail to produce a diagram that depicts the history of water motion past a given point. The asterisks and adjacent numbers are provided on the plots to indicate the beginning and the day of each measurement. By comparing the PROVECS for a given time period the relative velocity and direction of the flow past each mooring location can be determined. If the current is slow for a particular time period the asterisks will be closely spaced. Greater distance between asterisks indicates faster current for a particular period of time. Spaces in the PROVECS and dashed lines indicate missing data.

2. Current Drogue Measurements

Current measurements using drogues were made once every month during the period of April through November 1976 to estimate spatial variations in current speed and direction in the vicinity of KNPP. Drogue data could not be obtained during October sampling period due to the damage of navigation equipment located on shore. The window shade drogue (Figure 1.4) used for the measurements consisted of a 10 ft x 10 ft polyethylene panel weighted at one edge by an iron pipe and attached at the opposite edge to a length of conduit. Each polyethylene panel was suspended beneath



WINDOW SHADE DROGUE

Figure 1.4. Window shade current drogue used in Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant during 1976.

a surface buoy. Currents were measured at the surface and at depths of 10 ft and 30 ft below the water surface. The position of each drogue was periodically determined using a precision navigation system (Motorola Mini-Ranger).

B. Temperature Measurements

1. Time-Continuous Temperature Measurements

Time-continous temperature measurements were made concurrently with the current measurements. An ENDECO Type 109 recording thermograph (Figure 1.5) was attached to each mooring directly beneath the current meter. A thermograph at each of the three stations recorded half-hourly averages of temperature on 16 mm film with a resolution of 0.1 C and an accuracy of ±0.2 C. The time constant of the instrument is 10 min. The thermographs were serviced at the same time as the current meters. Servicing consisted of replacement of batteries, film, and dessicant bags.

C. Wind Measurements

Wind data were continously recorded from 17 June to 18 November 1976 near the KNPP observation building at a height of 33 ft above ground (75 ft above the water surface). A mechanical weather station (Meteorology Research Incorporated Model 1071) was used for these measurements. Wind direction and wind run (the linear miles of air which moves past the instrument) were continuously recorded on strip chart paper. The weather station was serviced monthly which included the replacement of batteries and strip-chart paper. The threshold speed of the instrument is 1.1 ft/sec. The wind run sensor has an accuracy of ±2% and is resolvable to

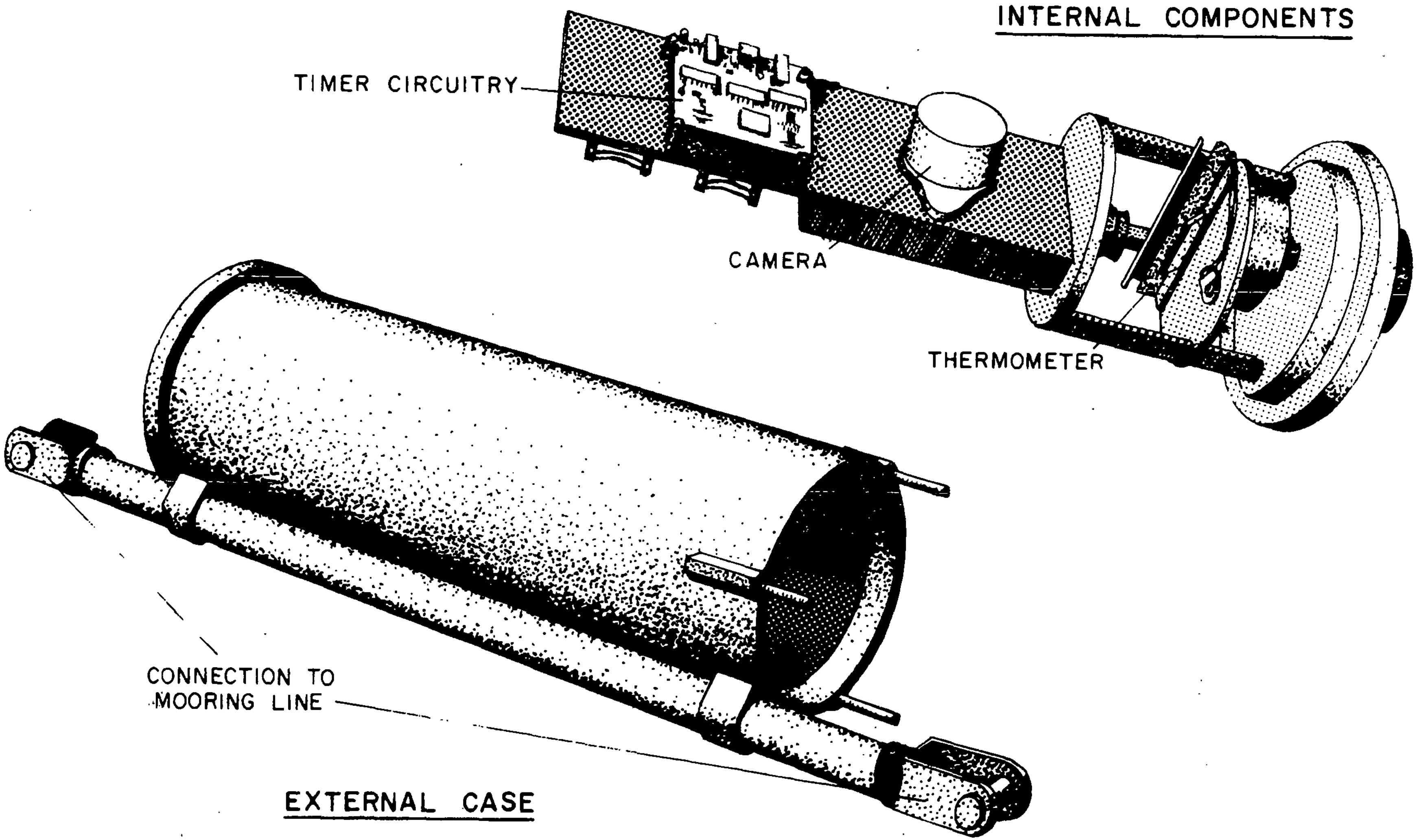


Figure 1.5. Recording thermograph (ENDECO Type 109) used in Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant during 1976.

0.5 mile. The wind direction sensor has an accuracy of 3.6 degrees but values can only be read in increments of 15 degrees.

Time series data of hourly vector averages of wind speed (wind run per unit time) and direction were used to construct plots of speed and direction versus time, progressive vector diagrams (PROVECS), joint frequency tables of wind speed and direction, and persistence tables of wind speed and direction.

III. Results and Discussion

A. Current Measurements

1. Time-Continuous Current Meter Measurements

The monthly time-continuous current data, which are presented in graphic form in Appendix 1-A and tabular form in Appendix 1-B, represent an 80 percent return of valid data for the entire measurement program.

A visual comparison of the current speed data obtained at each mooring location shows a good correlation among the locations during each month. A typical example of the agreement of current speed measured at each location is shown in Figure 1.6. The fluctuations in speed as measured at each station were strongly correlated in time but differed slightly in magnitude. The speeds measured at the Offshore Surface Station were generally faster than those at the other stations. Typical speeds ranged from 0.1 to 0.4 ft/sec and occasionally reached 0.6 ft/sec. The maximum speed recorded was 0.99 ft/sec which occurred during July 1976 at the Offshore Surface Station.

The monthly PROVECS of the current data records from each station are presented in Appendix 1-C. The direction of the flow at each individual station was sometimes observed to be different from the general direction of flow of the water mass; these were localized effects due to deflection caused by the bottom topography. These directional differences indicate a temporary interruption of the general water movement at a given station.

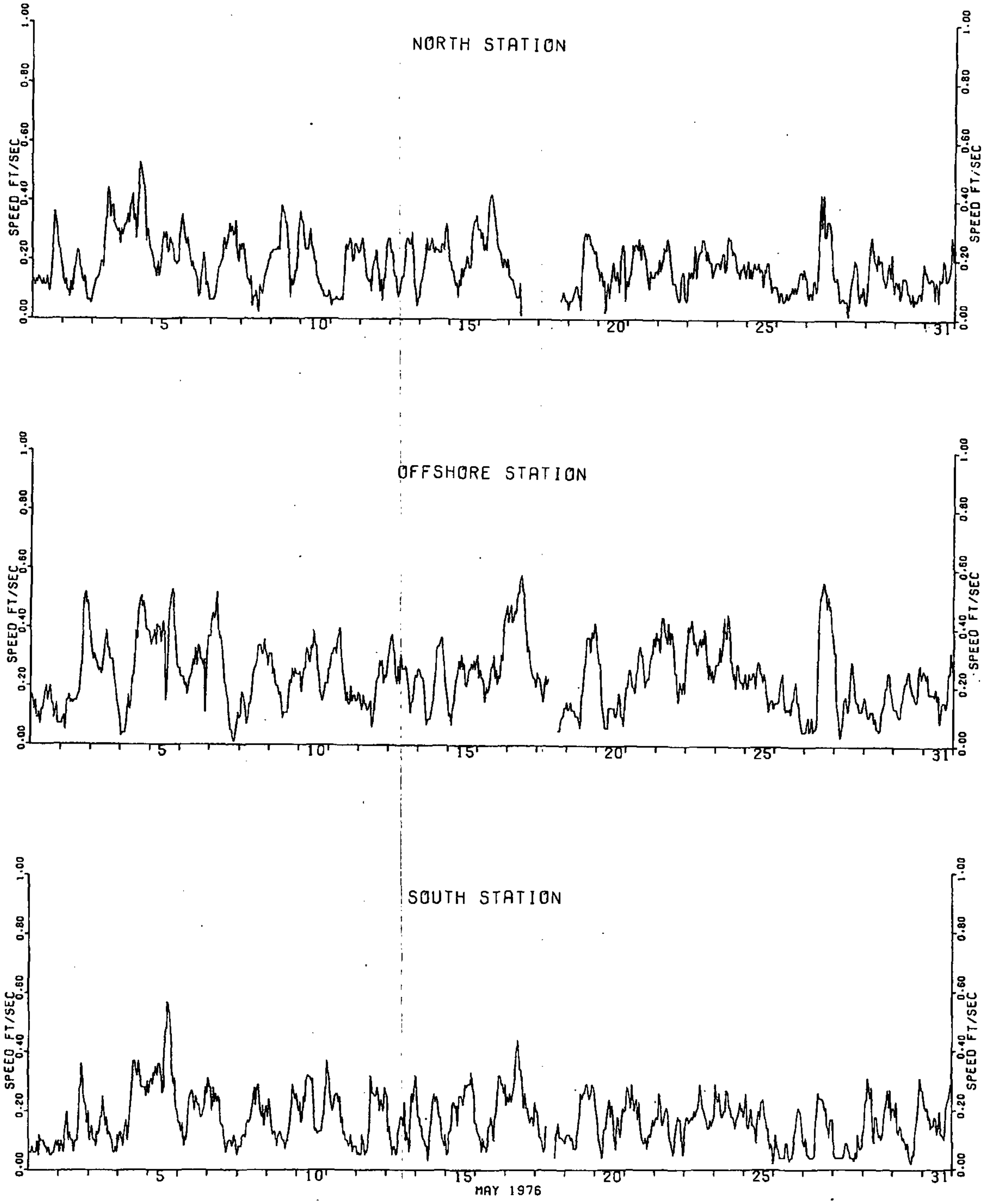


Figure 1.6. Time-continuous current speed measurements at each mooring location in Lake Michigan near the Kewaunee Nuclear Power Plant, May 1976.

A typical example of the PROVECS is presented in Figure 1.7 which shows the May 1976 current records. As shown in this figure, during the period 20 to 26 May, the current was moving south to southwest at all stations. Early on 26 May 1976, the current changed direction nearly simultaneously at the north and south stations and headed in a northeastward direction. On 27 May the current at the Offshore Station headed in a northeastward direction. The current direction changed again nearly simultaneously at all stations early on 28 May heading in a northwestward direction. By comparing the individual PROVECS for various time periods, it is seen that the water body moves essentially as a homogeneous mass. For a given time period, current speeds and directions among the stations differ somewhat probably due to bathymetric influences. However, changes in current speed and direction generally occur at all stations at the same time. A comparison of all available monthly PROVECS, both among themselves and with other data (such as wind and bathymetry), provide insight into the nature of the flow in the study area and how it is affected by other physical parameters.

A summary of the net water displacement, the direction of net displacement, the speed of net displacement, the average current speed and the individual record length for each monthly current record during the eight-month sampling period from April through November 1976 is given in Table 1.1. The net displacement is the distance a water parcel will travel during the month if it moves at measured velocity. The net water displacement past KNPP

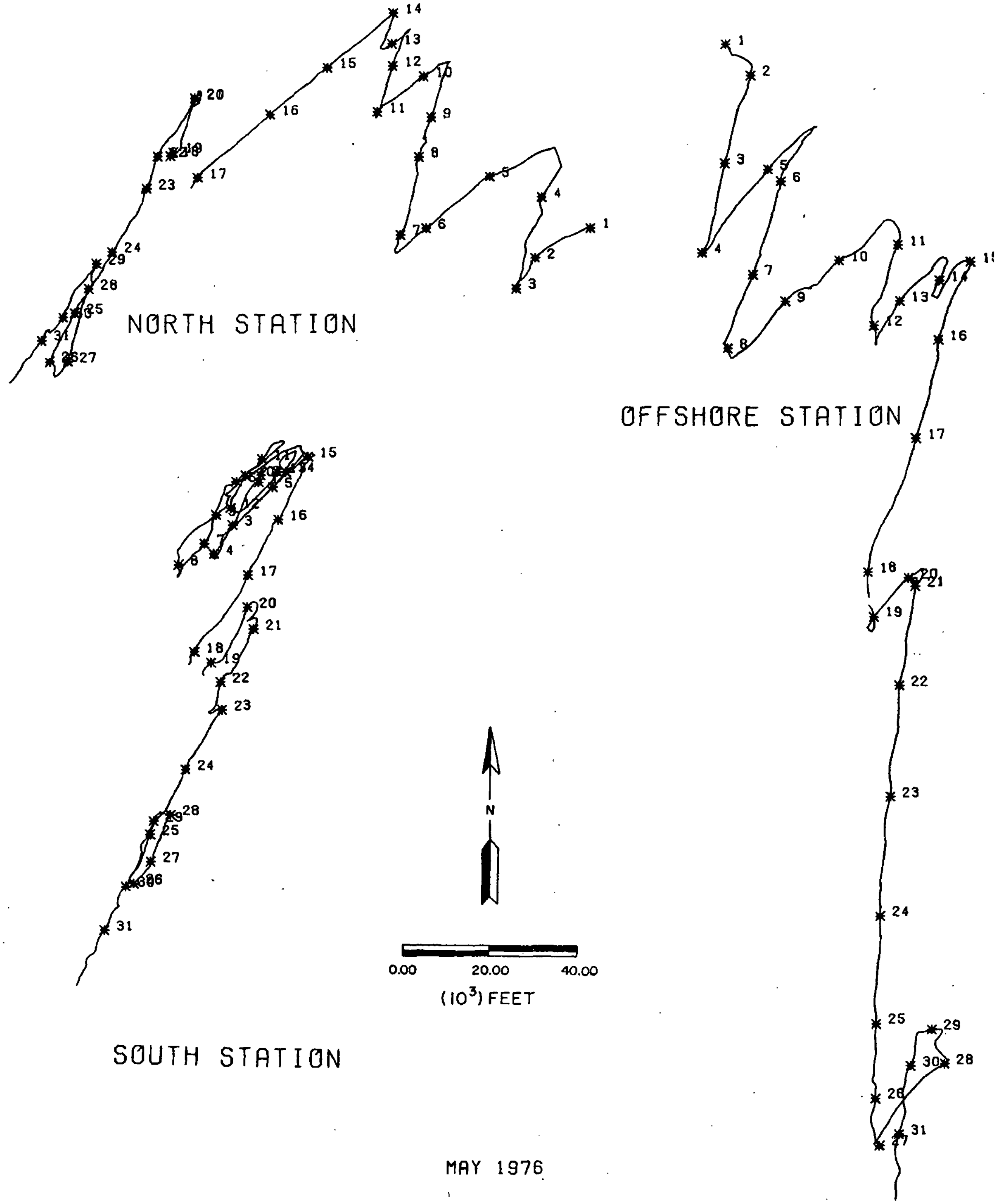


Figure 1.7. Progressive vector diagrams (PROVECS) of time-continuous measurements of currents in Lake Michigan near the Kewaunee Nuclear Power Plant, May 1976. (Asterisks and adjacent numbers indicate the beginning and date of each measurement day.)

Table 1.1. Comparison of time-continuous current meter and wind data recorded near the Kewaunee Nuclear Power Plant, April - November, 1976.

Parameter	Station	Month - 1976							
		April	May	June	July	Aug	Sept	Oct	Nov
Net Displacement 10^5 feet	North	0.27	1.37	0.54	0.34	2.11	0.53	-[a]	-
	Offshore	0.35	2.73	1.66	1.20	-	0.31	1.38	0.67
	South	0.23	1.24	1.53	1.29	1.39	0.46	0.49	0.38
	Wind	-	-	86.6	50.5	101.0	130.0	137.0	202.0
Direction of Net Displacement	North	15	252	52	86	07	352	-	-
	Offshore	23	172	71	92	-	260	260	213
	South	36	202	16	332	354	254	198	167
	Wind	-	-	47	122	23	97	125	93
Average Current Speed (ft/sec)	North	0.16	0.18	0.16	0.20	0.20	0.22	-	-
	Offshore	0.20	0.24	0.22	0.34	-	0.17	0.23	0.24
	South	0.18	0.17	0.17	0.20	0.21	0.16	0.18	0.16
	Wind	-	-	17.1	14.8	16.7	18.4	19.0	19.4
Record Dates	North	28-30	01-31	01-30	01-31	01-31	01-22	-	-
	Offshore	28-30	01-31	01-30	01-20	-	24-30	01-31	01-16
	South	29-30	01-31	01-30	01-31	01-31	01-30	01-31	01-16
	Wind	-	-	14-30	01-31	01-31	01-30	01-31	01-18

[a] No data were collected during this time period.

was generally shore-parallel toward the northeast and typical monthly average current speeds ranged from 0.16 ft/sec to 0.34 ft/sec with maximum mean speeds at the Offshore Surface Station. Typical monthly net displacements were between 0.3×10^5 ft and 2.1×10^5 ft. The maximum monthly net displacement of 2.73×10^5 ft at 172 deg. occurred at the Offshore Station in May.

Figure 1.8 graphically shows the net monthly water displacement at each Station. The length of the arrow is proportional to the displacement and the direction of the arrow indicates the direction of displacement with respect to true North. The net water displacement past KNPP was found to agree reasonably well with the general circulation patterns of Lake Michigan.

Monthly joint frequency tables of lake current speed and direction for each data record are presented in Appendix 1-D. Joint Frequency Tables show the frequency of joint occurrence of speed (by speed class) and direction (by direction sector). The column on the right of each table is the frequency of occurrence of each direction as a percentage of the total observations for that period. The bottom row represents the frequency of occurrence of speed by class also as a percentage of the total observations. Entries in the table represent the frequency of occurrence of the various velocity classes (Speed and direction).

The joint frequency tables showed a bimodal directional characteristic (the occurrence of two predominant current directions) and predominant speeds within the 0.10-0.25 ft/sec speed class. Figure 1.9 presents a graphical representation of the

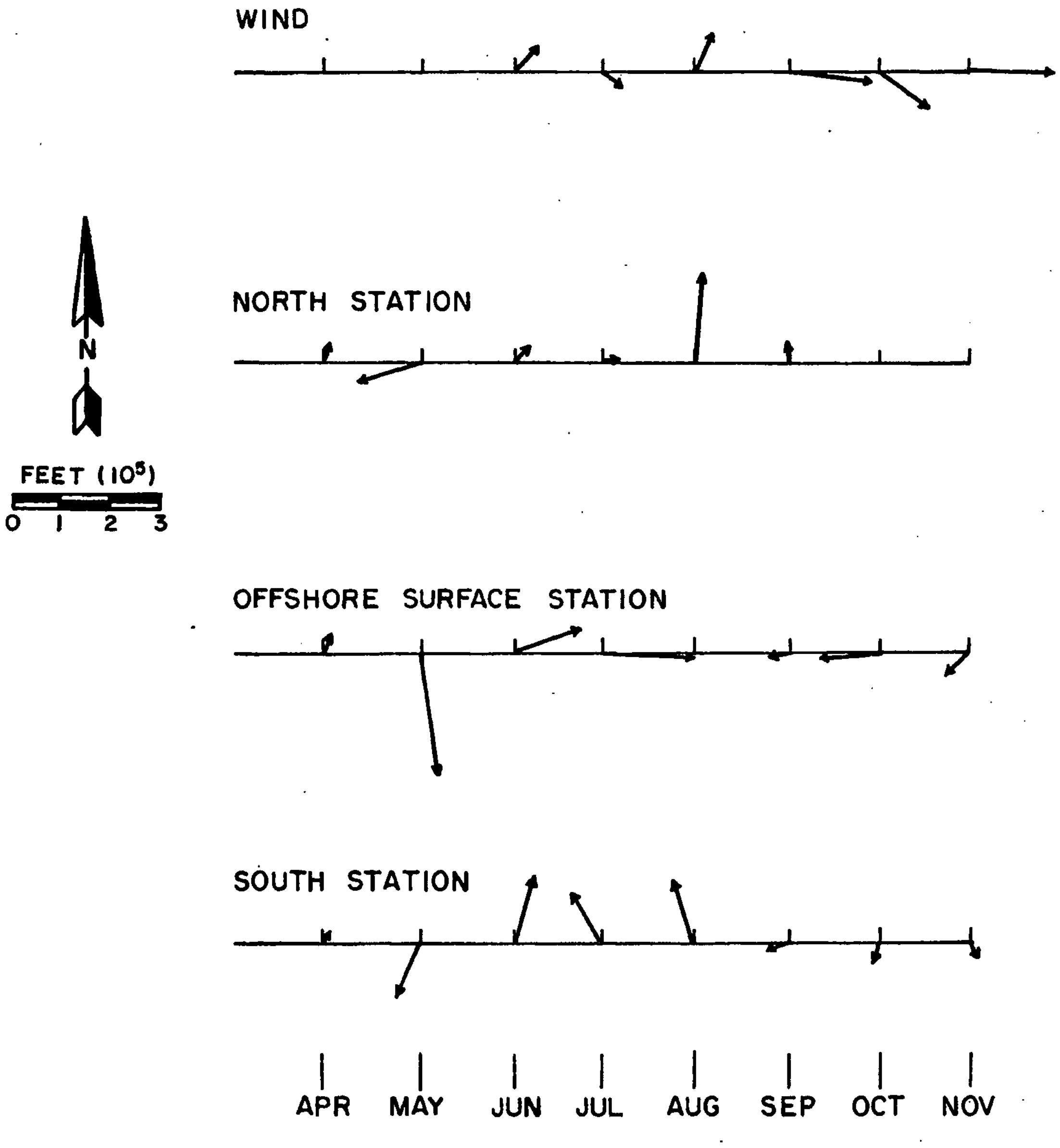


Figure 1.8. Monthly net water displacement in Lake Michigan and net wind displacement measured in the vicinity of Kewaunee Nuclear Power Plant, April-November 1976. (Wind displacement is actually 100X the scale shown. The length of the arrow is equivalent to the net displacement with respect to True North).

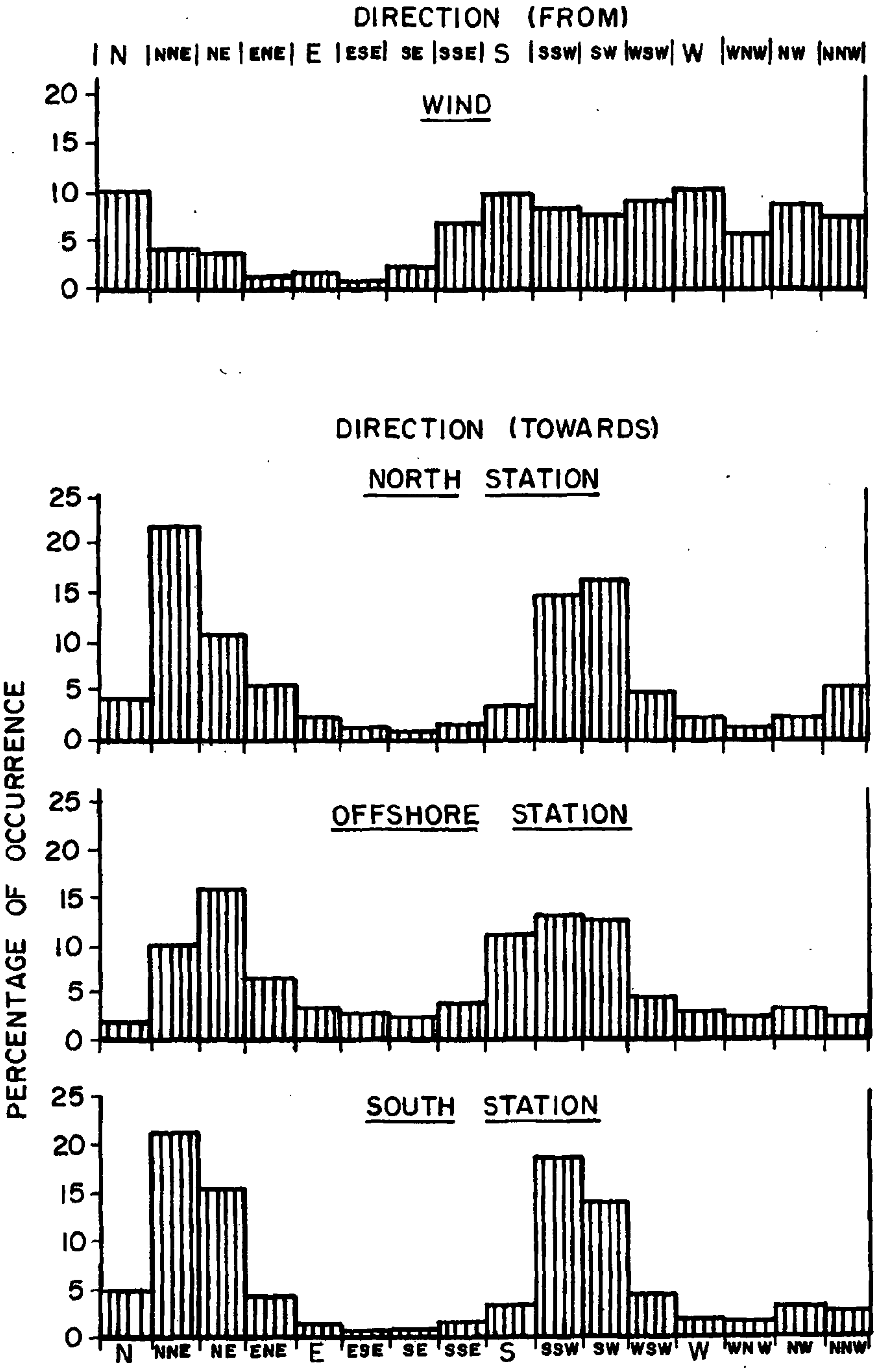


Figure 1.9. Histogram of Lake Michigan current and wind direction recorded in the vicinity of the Kewaunee Nuclear Power Plant, April-November 1976.

eight-month distribution of current direction and wind direction from April to November 1976 at each station. The bimodality is evidenced by the peaks located near the NNE-NE and the SSW-SW directions. At each station there is also a third but smaller peak near the NW-NNW direction. Figure 1.10 presents a graphical representation of the eight-month distribution of current speed and wind speed at each station. The higher speeds are most frequent at the Offshore Surface Station.

Persistence tables for current speed and current direction are presented in Appendices 1-E and 1-F, respectively. Persistence refers to the number of occurrences that a given parameter fell within a specified direction or speed class for a specified time period (1hr, 2hr, etc.). In each Persistence Table, the left column labeled "persistence" lists the persistence time in hours and the top row lists the direction or speed class. The row labeled "maximum" contains the greatest persistence (hours) observed for that class. The row labeled "total" contains the number of observations for that class. The left column labeled "percentiles" lists the percentiles of the total number of hours (or less) shown in that respective row. For example, a "4" in the 50 percentile row and the NE direction is to be interpreted as, "50 percent of the observations in the NE class had a persistence of 4 hours or less." The row labeled "sample size" indicates the number of hours of data contained in each class. The greatest persistence of current in a single direction was 38 hours toward the SSW. This occurred during June 1976 at the South Station. Direction persistence at all

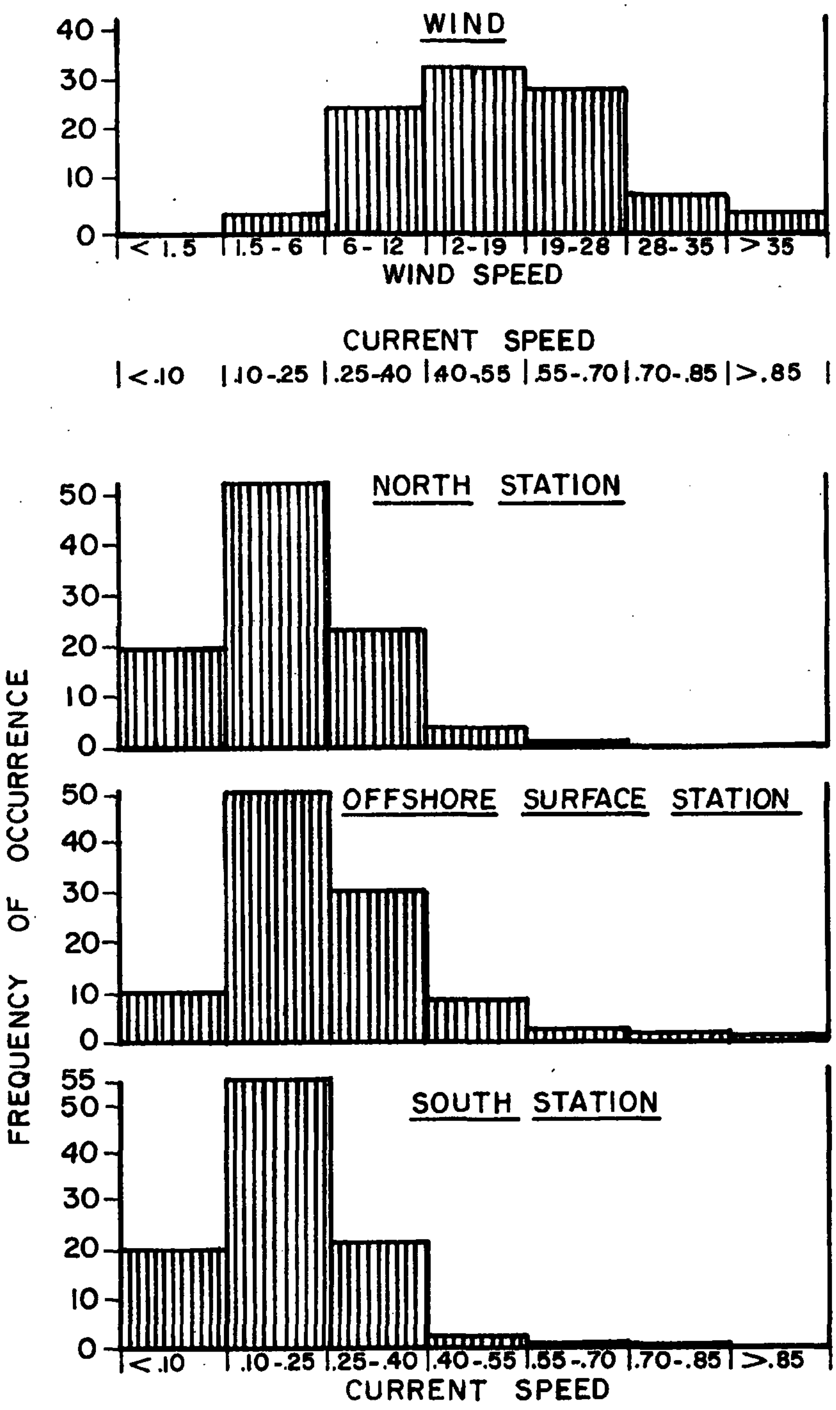


Figure 1.10. Histogram of Lake Michigan current and wind speed recorded in the vicinity of the Kewaunee Nuclear Power Plant, April-November 1976

stations was maximum in October and November 1976. Over the eight-month period of April through November 1976, the observed monthly maximum persistence occurred most frequently in the SSW-SW sectors.

The greatest speed persistence observed during the eight-month period of April through November 1976 was 37 hours at the South Station. This occurred between 27 and 30 September and the speed class was between 0.10-0.25 ft/sec. The monthly maximum persistence over the eight-month period was most frequently observed within the 0.10-0.25 ft/sec speed class. The Offshore Surface Station consistently recorded the greatest speed having a persistence of one hour or more. The greatest persistence speed class observed was the 0.85 ft/sec class for a maximum duration of 6 hours at the Offshore Surface Station on 9 July 1976.

2. <u>Current Drogue Measurement</u>

The drogue studies were intended to assess the spatial variations of lake current speed and direction in the vicinity of KNPP. The data presented in Appendix 1-G show both horizontal and vertical current shear. The average speeds measured at the surface were 0.11 ft/sec faster than those at a depth of 3 m, and 0.20 ft/sec faster than those at a depth of 9 m.

During the April and November 1976 studies, the direction of the net drogue travel at the surface and at a depth of 3 m differed by only a few degrees, while during July and August 1976 the angular difference ranged from 30 to approximately 250 degrees. The large angular deviations are a result of rapidly changing wind and current conditions.

There were slight differences in speed and direction of the net water flow as determined by the drogues compared to the current meter measurements. The speed of the current flow as determined by the movement of the drogues was usually greater than that determined by the current meters, which indicated that the drogues were somewhat wind sensitive. However, it is difficult and of ambiguous significance to make direct comparisons of drogue and current meter data except during those rare instances when the drogue physically moved past the current meter during a given study. Only under such a condition, the two devices are in fact measuring the same parcel of water. Water that has moved past a moored instrument at a given time is not necessarily moving with the same speed or in the same direction once it has passed that instrument. Consequently, it is not surprising that differences occurred between flow determined by drogue studies and flow determined by current meter data.

B. Temperature Measurements

1. Time-Continuous Temperature Measurements

The monthly time-continous temperature data, which are presented in graphic form in Appendix 1-H and tabular form in Appendix 1-I. Represent a 89 percent return of valid data for the entire measurement program. These data show good correlation among the three stations. Fluctuations in temperature occurred almost simultaneously at all stations which further attests to the homogeneity of movement of the water body as indicated by the time-continuous current data. Maximum, minimum and mean values of temperature from April through November 1976 are tabulated in Table 1.2. When making comparisons among the various stations, consideration must be given to the length of each record. The data collected either during different time periods or for significant different lengths of record cannot be directly correlated.

The presence of the thermal plume is frequently visible in the temperature records. For example, on 18 July 1976 when the current was moving toward the northwest at all current meter stations, a narrow temperature spike was visible in the North Station temperature record, but was absent from the South Station temperature records. Similarly, on 5 September 1976 during a southwestward current, a temperature spike was visible in the South Station temperature record but was absent from the North Station record.

C. Wind Measurements

The monthly time-continuous wind data, which are presented in graphic form in Appendix 1-J and tabular form in Appendix 1-K represent a 91 percent return of valid data for the entire measurement program. Wind speed and direction are also plotted against time and are shown with PROVECS of the same data. Typical wind speeds ranged from 10 to 30 ft/sec.

A summary of the net wind displacement, the direction of net displacement, the speed of net displacement, the average wind speed and the individual record length were determined for each monthly wind record for the six-month period from June through November is given in Table 1.1. The monthly net displacement of

Table 1.2. Monthly means and ranges of time-continuous recordings of temperature in Lake Michigan near the Kewaunee Nuclear Power Plant during 1976.

	Mooring					
	North		Offshore Surface		South	
Month	Temperature (°C)	Record Length (hr)	Temperature (°C)	Record Length (hr)	Temperature (°C)	Record Length (hr)
April						
Mean	7.1	35	5.7	58	7.1	37
Range	6.5-7.6		4.9-6.6		6.5-7.6	
May						
Mean	8.6	737	7.5	736	8.0	418
Range	5.7-12.2		4.9-11.4		6.2-9.6	
June						
Mean	9.1	698	9.8	698	9.1	350
Range	6.1-14.0		6.4-14.5		6.8-12.4	
July						
Mean	14.6	720	15.2	721	15.2	722
Range	7.1-18.9		8.3-18.6		9.0-19.3	
August						
Mean	15.9	739	16.7	737	16.3	741
Range	7.1-19.8		8.0-20.5		8.1-20.2	
September						
Mean	14.5	454	14.8	676	14.5	676
Range	11.0-17.7		10.5-17.5		11.3-17.7	
October						
Mean	10.3	714	10.6	741	13.3	446
Range	5.4-15.5		6.1-15.0		10.0-15.9	
November						
Mean	5.0	304	5.0	373	-[a]	-
Range	1.8-7.3		3.0-7.1			

[a] No data were collected for this time period.

wind past KNPP ranged between 5.1 x 10^6 ft and 20.2 x 10^6 ft and was generally toward the northeast. The monthly average wind speed ranged from a minimum of 14.8 ft/sec in July to a maximum of 19.4 ft/sec in June.

Comparison of the net displacements of wind and water during periods of maximum record length implies typical monthly net displacements. Net displacements for similar time periods show 8.20 x 10^4 ft and 505 x 10^4 ft as representative monthly displacements of current and wind, respectively. From these comparisons one may infer that for every 60 ft of wind displacement there is an approximate displacement of 1 ft of water.

Figure 1.8 graphically shows the net monthly wind displacement for each month of record. The length of the arrow is proportional to the displacement and the direction of the arrow indicates the direction of displacement with respect to true North. The predominant direction of net displacement among wind and current shows good agreement.

Monthly joint frequency tables of wind speed and direction are presented in Appendix 1-L. Figure 1.9 is a graphical representation of the six-month distribution of wind direction. from June to November 1976. The modality is evidenced by the peaks located near the S and the W directions. On the six-month scale, it is obvious that the bimodality observed in the current records is defined in the wind records. However, the predominant direction of the wind is from the south and west and varies between WNW and NE. Winds infrequently blow from NE. There is also a third peak near the N direction. In the same graph, the currents show predominant directions toward SSW-SW and NNE-NE. These directions are directly related to the shoreline and the bathymetric contours of the study area. The SSW current directions occur during winds toward the ESE-SE while NNE-NE currents coincide with generally northward moving wind.

The predominant wind speed class increased from 6-12 ft/sec in June-July to 12-19 ft/sec in August, September and October and increased again to 19-28 ft/sec in November. Figure 1.10 is a graphical representation of the six-month distribution of wind speed. The predominant speeds recorded are indicated by the peak at the 12-19 ft/sec speed class.

Persistence tables for wind speed and wind direction are presented in Appendices 1-M and 1-N, respectively. The wind direction is defined as the direction from which the wind is blowing. The direction classes of greatest persistence are found to be concentrated in the N and SSE-NNW sectors. The greatest persistence of wind direction in a single sector was wind from the NNW for 18 hours which occurred in October 1976.

The maximum persistence of wind speed for the first four months (June-September 1976) was 18 hrs in the 19-28 ft/sec class in July, and 18 hrs in the 12-19 ft/sec speed class in September. During October and November 1976, the maximum persistence was in the 12-19 ft/sec class. The greatest persistence of wind speed was 22 hours for 12-19 ft/sec speeds which occurred on 16-17 October 1976. The maximum recorded speed was 54.1 ft/sec on 30 June.

IV. Summary and Conclusions

1. The data collected describe the spatial and temporal near-shore water circulation and temperature structure, and the wind distribution in the vicinity of KNPP for the April-November 1976 measurement period.

2. The water mass movement in the area of KNPP is spatially homogeneous. The current speed and direction are influenced by the bottom topography and the prevailing local winds.

3. The net water displacement past the KNPP was generally shore-parallel toward the northeast. Average monthly current speeds range between 0.16 ft/sec and 0.34 ft/sec. The maximum current speed recorded was 0.99 ft/sec.

4. The greatest persistence of current in a single direction was 38 hours toward the SSW and the greatest persistence of current speed was 37 hours for speeds within the 0.10-0.25 ft/sec class.

5. Periods of greatest monthly temperature range occurred during July and August 1976. This range was found to be as great as 12.7 C.

6. A maximum temperature of 20.5 C was recorded during August 1976 at the Offshore Station and a minimum temperature of 1.8 C was recorded during November 1976 at the North Station.

7. Net wind displacement past the KNPP was generally toward the northeast. Average monthly wind speeds ranged from 14.8 to 19.4 ft/sec. The maximum wind speed recorded was 54.1 ft/sec.

8. The greatest persistence of wind in a single direction was 18 hours from the NNW and the greatest persistence of wind speed was 22 hours for speeds between 12-19 ft/sec.

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Chapter 2

WATER CHEMISTRY AND BACTERIOLOGY

David B. Ellis

OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR
KEWAUNEE NUCLEAR POWER PLANT

SIXTH ANNUAL REPORT
January - December 1976

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Chapter 2

WATER CHEMISTRY AND BACTERIOLOGY

David B. Ellis

I. Introduction

This chapter contains the results of the third year of operational monitoring of the chemical and bacteriological quality of Lake Michigan water in the vicinity of the Kewaunee Nuclear Power Plant (KNPP). The specific objectives of the 1976 study were:

1. to monitor existing water quality in the vicinity of the Plant;
2. to compare the existing water quality with state standards adopted by the Wisconsin Department of Natural Resources and contained in the Wisconsin Administrative Code;
3. to determine the seasonal and spatial variations in the concentrations of the parameters measured;
4. to establish whether or not domestic sewage or agricultural wastes may be present in the waters near KNPP; and
5. to compare the 1976 operational water quality data with the 1974 and 1975 operational water quality data and also with those of the preoperational monitoring program conducted in 1973 and in previous years.

II. Field, Analytical and Data Analysis Procedures

A. Sampling Locations and Frequency

Water samples for chemical and bacteriological analyses were collected monthly from April through November 1976 at seven lake sampling locations along five transects (Figure 1 and Table 1, Introduction) as follows: samples collected at the three locations along the 10-ft depth contour were taken at mid-depth (Mid); samples collected at the three locations along the 20-ft contour were taken at one meter below the surface (Top) and at one meter above the bottom (Bot); and samples collected at the one location along the 40-ft contour were taken at one meter below the surface, at mid-depth and at one meter above the bottom. A description of the transect locations, the sampling locations and depth contours within each transect are presented in Table 2.1. Each of the water samples collected was analyzed to determine the concentration of those parameters listed in Table 2.2.

Water temperature, dissolved oxygen, pH and specific conductance measurements were taken *in situ* at the surface and at every meter of depth at 17 lake sampling locations (Figure 1 and Table 1, Introduction). Meteorological measurements were also recorded in the field at the seven water quality sampling locations.

B. Field Procedures

Duplicate water samples for chemical analyses were collected using simultaneous casts of non-metallic Van Dorn water samplers at each of the seven locations in Lake Michigan. Duplicate samples for bacteriological analyses were also collected simultaneously,

Table 2.1. Sampling locations and depths along transects in Lake Michigan near the Kewaunee Nuclear Power Plant during 1976.

Transect	Lake Depth Contour	Sampling Location	Sampling Depth	Description of Transect
I	10 ft	2	Mid	2.0 miles north of KNPP
II	20 ft	7	Top, Bot	0.5 miles north of KNPP
III	10 ft	11	Mid	Directly in front of KNPP
	20 ft	12	Top, Bot	
	40 ft	14	Top, Mid, Bot	
IV	20 ft	16	Top, Bot	0.5 miles south of KNPP
V	10 ft	20	Mid	2.5 miles south of KNPP

Table 2.2. Chemical and bacteriological parameters determined in Lake Michigan water samples during 1976.

General Water Quality Parameters

1. Alkalinity, total
2. Calcium
3. Chloride
4. Color, true
5. Conductance, specific[a]
6. Fluoride
7. Hardness, total
8. Magnesium
9. Oxygen, dissolved[a]
10. Oxygen, saturation
11. pH[a]
12. Potassium
13. Residue, filtrable (total dissolved solids)
14. Residue, nonfiltrable (total suspended solids)
15. Residue, total (total solids)
16. Sodium
17. Sulfate
18. Temperature[a]
19. Turbidity

Aquatic Nutrients

20. Ammonia
21. Nitrate
22. Nitrite
23. Organic nitrogen, total
24. Orthophosphate, soluble
25. Phosphorus, total
26. Silica, soluble

Indicators of Industrial and Municipal Contamination

27. Bacteria, standard plate count (20.0C)
28. Bacteria, total coliform
29. Bacteria, fecal coliform
30. Bacteria, fecal streptococc
31. Biochemical oxygen demand (5-day)
32. Chemical oxygen demand
33. Hydrazine
34. Organic carbon, total

Trace Elements

35. Arsenic
36. Boron
37. Cadmium
38. Chromium, total
39. Copper
40. Iron, soluble
41. Iron, total
42. Lead
43. Manganese
44. Mercury
45. Nickel
46. Zinc

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[a] Indicates an *in situ* measurement.

and at the same times and locations as the chemical samples, using a modified Zobell bacteriological water sampler (A.P.H.A. et al. 1976).

The general procedure for collecting samples for water quality at each of the lake locations followed that of phytoplankton so that appropriate water quality and biological correlations were possible.

In situ measurements of the water quality parameters profiling the water column were performed using a Hydrolab Surveyor Model 6D *in situ* Water Quality Analyzer (Hydrolab Corporation 1973). The Hydrolab Surveyor was calibrated as follows: the temperature probe was checked against a precision, mercury-filled, centigrade thermometer; the dissolved oxygen probe was standardized by comparison with duplicate Winkler determinations (A.P.H.A. et al. 1976); the specific conductance and pH probes were calibrated against internal standards, the pH probe using standard 7.0 and 10.0 buffer solutions.

The instrumentation, methodology and precision of measurement for meteorological parameters recorded at the time of sampling are presented in Table 2.3.

All water samples were appropriately preserved at the time of collection and returned to the laboratory for analysis. Those samples requiring refrigeration were placed in insulated cartons, packed in ice and kept refrigerated until analyses were performed.

C. Analytical Procedures

The analytical methods, preservation techniques, detection

Table 2.3. Meteorological measurements and instrumentation used in the vicinity of the Kewaunee Nuclear Power Plant during 1976.

Measurement	Instrument	Precision of Measurement
Air temperature, wet and dry bulb	Bendix Psychrometer Model 566 or Taylor Sling Psychrometer	±0.5C
Cloud cover	Field Observer	±5%
Relative humidity	Computer Calculated	±1%
Wind		
direction	Field Observer	±22.5°
speed	Dwyer Wind Meter	±1 mph

limits and references are presented in Tables 2.4 through 2.7 for all chemical and bacteriological parameters measured during this study. All analytical methods followed Standard Methods for the Examination of Water and Wastewater (A.P.H.A. et al. 1976) or were approved by the U.S. Environmental Protection Agency (1974).

D. Quality Assurance Procedures

The quality assurance program in the chemical and bacteriological laboratories follows the NALCO ES Quality Assurance Manual. It is based on the Handbook for Quality Assurance Procedures in Water and Wastewater Laboratories (U.S.E.P.A. 1972) and complies with requisities described in Minimal Requirements for a Water Quality Assurance Program (U.S.E.P.A. 1976); including calibrating sampling equipment and field instruments; sample collection and preservation techniques; laboratory analysis; recording, storing and retrieving data; and chain-of-custody. The bacteriological laboratory is certified by the Illinois Public Health Department; their records and procedures comply with the requirements of the USEPA.

E. Data Analysis Procedures

Several methods of statistical treatment were employed to analyze the water chemistry and bacteriology data. Monthly means were calculated for each parameter by combining all values at all locations. The result was an overview of conditions existing in the Lake Michigan waters for each chemical and bacteriological parameter on a month-to-month basis.

Annual descriptive statistics consisting of the mean,

Table 2.4. Methods for the analysis of general water quality parameters.

Constituent	Method	Preservation Technique	Reference	Detection Limit
Alkalinity, total	Potentiometric, titrimetric	Refrigeration	Method 403, A.P.H.A. et al. 1976	1 mg/l-$CaCO_3$
	Autoanalyzer	Refrigeration, filtration, 0.45 µm membrane filter	U.S.E.P.A. 1974	2 mg/l-$CaCO_3$
Calcium	Atomic absorption direct aspiration	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1968	2 µg/l
Chloride	Mercuric nitrate	None required	Method 408B A.P.H.A. et al. 1976	0.5 mg/l
	Autoanalyzer Ferricyanide	None required	Method 602 A.P.H.A. et al. 1976	0.1 mg/l
Color, true and apparent	Pt-Co	None required	U.S.E.P.A. 1974	1 unit
Conductance, specific	Hydrolab Surveyor	Measured *in situ*	Method 205 A.P.H.A. et al. 1976 Hydrolab Corp. 1973;	1 µmho/cm
	Laboratory conductivity meter	None required	Method 205 A.P.H.A. et al. 1976	1 µmho/cm
Fluoride	Electrode method	None required	Method 414B A.P.H.A. et al. 1976	0.01 mg/l
Hardness, total	Calculated	-	Method 309A A.P.H.A. et al. 1976	1 mg/l-$CaCO_3$
Iron[a]	Atomic absorption direct aspiration	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1968	0.03 mg/l
	Atomic absorption chelation	HNO_3	U.S.E.P.A. 1974; Fishman and Midgett 1968	1 µg/l
	Atomic absorption graphite atomizer	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1972a	0.5 µg/l
Magnesium	Atomic absorption direct aspiration	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1968	1 µg/l
Manganese	Atomic absorption direct aspiration	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1968	0.01 mg/l
	Atomic absorption chelation	HNO_3	U.S.E.P.A. 1974; Fishman and Midgett 1968	1 µg/l
	Atomic absorption graphite atomizer	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1972a	0.1 µg/l
Oxygen, dissolved	Hydrolab Surveyor, or oxygen analyzer, membrane electrode	Measured *in situ*	Methods 422F and 422B A.P.H.A. et al. 1976; Hydrolab Corp. 1973	0.1 mg/l
	Azide Modified Winkler titration	Measured in the field	Method 422B A.P.H.A. et al. 1976	0.1 mg/l
Oxygen saturation	Calculated	-	Method 422B A.P.H.A. et al. 1976	1%

Table 2.4. (continued)

Constituent	Method	Preservation Technique	Reference	Detection Limit
pH	Hydrolab Surveyor, potentiometric	Measured *in situ*	Method 424 A.P.H.A. 1976, Hydrolab Corp. 1973	0.1 pH
	Potentiometric	Measured in the field	Method 424 A.P.H.A. et al. 1976	0.1 pH
Potassium	Atomic absorption direct aspiration	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1968	5 µg/l
Residue, filtrable (total dissolved solids)	Filtration, gravimetry at 103-105C	None required	Method 208C A.P.H.A. et al. 1976	2 mg/l
Residue, non-filtrable (total suspended solids)	Filtration then gravimetry at 103-105C or by difference	None required	Method 208D A.P.H.A. et al. 1976	1 mg/l
Residue, total (total solids)	Gravimetry at 103-105C	None required	Method 208A A.P.H.A. et al. 1976	2 mg/l
Sodium	Atomic absorption direct aspiration	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1968	2 µg/l
Sulfate	Turbidimetric	None required	Method 427C A.P.H.A. et al. 1976	5 mg/l
	Autoanalyzer Methyl thymol Blue method	None required	Method 607 A.P.H.A. et al. 1976	1 mg/l
Temperature	Hydrolab Surveyor, or Whitney Thermometer	Measured *in situ*	Method 162 A.P.H.A. et al. 1976; Hydrolab Corp. 1973	0.1 C
Turbidity	Hach Turbidimeter, nephelometric	None required	Method 214A A.P.H.A. et al. 1976	0.1 N.T.U.

[a] Soluble iron was determined by filtering a portion of the sample and then applying the appropriate atomic absorption method.

Table 2.5. Methods for the analysis of aquatic nutrients.

Constituent	Method	Preservation Technique	Reference	Detection Limit
Ammonia	Gas diffusion electrode	$HgCl_2$, refrigeration	Thomas and Booth 1973; Howe and Holley 1969	0.01 mg/l-N
	Phenate Method	$HgCl_2$, refrigeration	Method 418C A.P.H.A. et al. 1976; Howe and Holley 1969	0.01 mg/l-N
	Autoanalyzer Phenate Method	$HgCl_2$, refrigeration	Method 604 A.P.H.A. et al. 1976; Howe and Holley 1969	0.01 mg/l-N
Nitrate	Brucine Method	$HgCl_2$, refrigeration	Method 419D A.P.H.A. et al. 1976; Howe and Holley 1969	0.01 mg/l-N
	Autoanalyzer cadmium reduction	$HgCl_2$, refrigeration	Method 605 A.P.H.A. et al. 1976; Howe and Holley 1969	0.01 mg/l-N
Nitrite	Diazotization method	$HgCl_2$, refrigeration	Method II.6. Strickland and Parsons 1972; Howe and Holley 1969	0.1 µg/l-N
Organic nitrogen, total	Kjeldahl method, subtract ammonia	$HgCl_2$, refrigeration	Method 421 A.P.H.A. et al. 1976; Howe and Holley 1969	0.01 mg/l
Orthophosphate, soluble	Ascorbic acid	Filtration, 0.45 µm membrane filter, refrigeration	Method II.1. Strickland and Parsons 1972; Ryden et al. 1972	1 µg/l-P
Phosphorus, total	Digestion then ascorbic acid method	None required	Method 425C A.P.H.A. et al. 1976; then method II.1 Strickland and Parsons 1972	1 µg/l-P
Silica, soluble	Heteropoly blue method	Filtration, 0.45 µm membrane filter	Method 426C A.P.H.A. et al. 1976	0.01 mg/l-Si
	Autoanalyzer Heteropoly blue method	Filtration, 0.45 µm membrane filter	Method 105-71 W Technicon Industrial Systems 1974	0.01 mg/l-Si

Table 2.6. Methods for the analysis of indicators of industrial and municipal contamination.

Constituent	Method	Preservation Technique	Reference	Detection Limit
Bacteria, standard plate count at 20.0C	Membrane filtration	$Na_2S_2O_3$, sterile bottle, refrigeration	Slack et al. 1973	0 colonies/ 100 ml
Bacteria, fecal coliform	Membrane filtration	$Na_2S_2O_3$, sterile bottle, refrigeration	Method 909C A.P.H.A. et al. 1976	0 colonies/ 100 ml
	Delayed incubation, membrane filtration	$Na_2S_2O_3$, sterile bottle, refrigeration	Method 909D A.P.H.A. et al. 1976	0 colonies/ 100 ml
Bacteria, fecal streptococci	Membrane filtration	$Na_2S_2O_3$, sterile bottle, refrigeration	Method 910B A.P.H.A. et al. 1976	0 colonies/ 100 ml
	Delayed incubation, membrane filtration	$Na_2S_2O_3$, sterile bottle, refrigeration	Millipore Corp. 1973	0 colonies/ 100 ml
Bacteria, total coliform	Membrane filtration	$Na_2S_2O_3$, sterile bottle, refrigeration	Method 909A A.P.H.A. et al. 1976	0 colonies/ 100 ml
	Delayed incubation, membrane filtration	$Na_2S_2O_3$, sterile bottle, refrigeration	Method 909B A.P.H.A. et al. 1976	0 colonies/ 100 ml
Biochemical oxygen demand (5-day)	Membrane electrode	Refrigeration	Method 507 A.P.H.A. et al. 1976	0.5 mg/l
Chemical oxygen demand	Low level method	Refrigeration	U.S.E.P.A. 1974	0.1 mg/l
Hydrazine	p-dimethylaminobenzaldehyde method	HCl, refrigeration	Method D 1385-67 A.S.T.M. 1973	4 µg/l
Organic carbon, total	Combustion infrared method	HCl, refrigeration	Method 505 A.P.H.A. et al. 1976; Ocean. Int. Corp. 1974a, b	1 mg/l
	Ocean. Int. Analyzer wet oxidation	HCl, refrigeration	Ocean. Int. Corp. 1974b	0.2 mg/l

Table 2.7. Methods for the analysis of trace elements.

Constituent	Method	Preservation Technique	Reference	Detection Limit
Arsenic	Atomic absorption direct aspiration	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1968	1 mg/l
	Atomic absorption AsH_3	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1972b	1 µg/l
	Atomic absorption graphite atomizer	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1972a	1 µg/l
Boron	Dianthrimide method	None required	Levinson 1971	0.01 mg/l
Cadmium	Atomic absorption direct aspiration	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1968	0.01 mg/l
	Atomic absorption chelation	HNO_3	U.S.E.P.A. 1974; Fishman and Midgett 1968	0.1 µg/l
	Atomic absorption graphite atomizer	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1972a	0.02 g/l
Chromium, total	Atomic absorption direct aspiration	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1968	0.03 mg/l
	Digestion, atomic absorption chelation	HNO_3	U.S.E.P.A. 1974; Fishman and Midgett 1968	1 µg/l
	Atomic absorption graphite atomizer	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1972a	0.1 µg/l
Copper	Atomic absorption direct aspiration	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1968	0.01 mg/l
	Atomic absorption chelation	HNO_3	U.S.E.P.A. 1974; Fishman and Midgett 1968	0.1 µg/l
	Atomic absorption graphite atomizer	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1972a	0.2 µg/l
Lead	Atomic absorption direct aspiration	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1968	0.1 mg/l
	Atomic absorption chelation	HNO_3	U.S.E.P.A. 1974; Fishman and Midgett 1968	1 µg/l
	Atomic absorption graphite atomizer	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1972a	1 µg/l
Mercury	Flameless atomic absorption	HNO_3	U.S.E.P.A. 1974	0.05 µg/l
Nickel	Atomic absorption direct aspiration	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1968	0.03 mg/l
	Atomic absorption chelation	HNO_3	U.S.E.P.A. 1974; Fishman and Midgett 1968	1 µg/l
	Atomic absorption graphite atomizer	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1972a	1 µg/l

Table 2.7. (continued)

Constituent	Method	Preservation Technique	Reference	Detection Limit
Zinc	Atomic absorption direct aspiration	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1968	0.01 mg/l
	Atomic absorption chelation	HNO_3	U.S.E.P.A. 1974; Fishman and Midgett 1968	1 µg/l
	Atomic absorption graphite atomizer	HNO_3	U.S.E.P.A. 1974; P-E Corp. 1972a	0.1 µg/l

mimimum and maximum values were calculated for each parameter for the top, middle and bottom waters at each location. The purpose of these calculations was to describe the concentrations of each parameter at each location and depth and to provide a basis for comparison with data gathered in previous years (Gara and Hawley 1974, Ellis 1975, 1976) as well as for comparison with data from other investigators, whenever available.

The water quality in the immediate discharge area of KNPP (Locations 11) was statistically compared to that of control areas at the same depth contour (Locations 2 and 20). The values measure at Location 11 for each parameter over the eight-month study period were pooled, and the mean was compared to the mean for pooled data from Locations 2 and 20 by employing a one-way analysis of variance

The monthly profile data of temperature and dissolved oxygen were plotted versus depth for each location. Also plotted were the calculated values for oxygen saturation and stability. These illustrations were drawn to show the effect of stratification, mixing and air temperature (seasonal) upon these parameters at various depths.

III. Results and Discussion

Data from samples collected and analyzed during 1976 are presented in: Appendix 2-A, results of analyses of chemical and bacteriological parameters; Appendix 2-B, the yearly means and ranges for these parameters according to sampling locations; Appendix 2-C, vertical profiles of temperature, dissolved oxygen, oxygen saturation, specific conductance and pH; and Appendix 2-D, physical and meteorological data. The Plant was operational on all sampling dates in 1976.

A. Comparison of Data to State Water Quality Standards

Lake Michigan water quality in the vicinity of KNPP complied with the standards adopted by the Wisconsin Department of Natural Resources (WDNR), as contained in Wisconsin Administrative Code, Chapter NR 102, July 1975 (Table 2.8). These Lake Michigan standards are for public water supplies, recreational use and for fish and other aquatic life.

It should be noted that two of the 23 samples analyzed in July contained fecal coliform densities greater than 400 organisms per 100 ml. However, the waters complied with the standards since counts did not exceed this value in more than 10% of the samples for this month.

B. Physical, Chemical and Bacteriological Characteristics of Lake Michigan in the Study Area

1. Temperature

The mean water temperature for the April through November study period was 9.6 C and the monthly means ranged from

Table 2.8. Wisconsin water quality standards applicable to the Kewaunee Nuclear Power Plant.

Parameter	Existing Standards[a]		No. of samples which exceeded the standards
Temperature	April	55F (12.8C)	0
	May	60F (15.5C)	0
	June	70F (21.1C)	0
	July	80F (26.6C)	0
	August	80F (26.6C)	0
	September	80F (26.6C)	0
	October	65F (18.3C)	0
	November	60F (15.5C)	0
Dissolved oxygen	5.0 mg/l minimum[b]		0
pH	6.0 - 9.0[b]		0
Residue, filtrable (total dissolved solids)	750 mg/l maximum[c]		0
Bacteria, fecal coliform	Not to exceed 400 per 100 ml in more than 10% of all samples during any month[d]		0
Substances that will cause objectionable deposits on the shore or in the bed of a body of water, shall not be present in such amounts as to interfere with public rights in waters of the state.			0
Floating or submerged debris, oil, scum or other material shall not be present in such amounts as to interfere with public rights in waters of the state.			0
Materials producing color, odor, taste or unsightliness shall not be present in such amounts as to interfere with public rights in waters of the state.			0
Substances in concentrations or combinations which are toxic or harmful to humans shall not be present in amounts found to be of public health significance, nor shall substances be present in amounts which are acutely harmful to animal, plant or aquatic life			0

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[a] Existing standards contained in the Wisconsin Administrative Code, Chapter NR 102, July 1975.

[b] Standard for fish and aquatic life.

[c] Standard for public water supply.

[d] Standard for recreational use waters.

4.3 C to 15.5 C. The lowest temperatures during this period occurred in the spring and fall and the highest in mid-summer (Figure 2.1).

Thermal influence of Plant operation usually was indicated by higher temperatures directly in front of the discharge at Locations 10, 11 and 12. In August the plume extended in a northerly direction from the discharge and could also be detected at Location 7. (These effects are illustrated seasonally by May, August and October in Figure 2.2.). In September the plume extended in a southerly direction and was detected at Location 17. During April and May the area of the thermal plume was small compared to the other months and temperature increases large enough to be attributed to KNPP rather than to solar warming were not detected at the chemistry sampling locations (Appendix 2-C, Table 3). When the thermal effects of KNPP were detected, they were limited to the upper three meters of the water column (Figure 2.2).

A well defined thermocline was present in July and August. The thermocline was detected at locations along the 20, 30, and 40-ft depth contours (Locations 3,4,7,8, 13 and 14) on 20 July and at all but a few nearshore locations on 24 August.

The lake was reasonably well-mixed in the other months, with slight temperature decreases with depth commonly occurring.

2. Dissolved Oxygen and Saturation

The mean dissolved oxygen (D.O.) concentration for the entire study period was 11.2 mg/l. High D.O. concentrations in

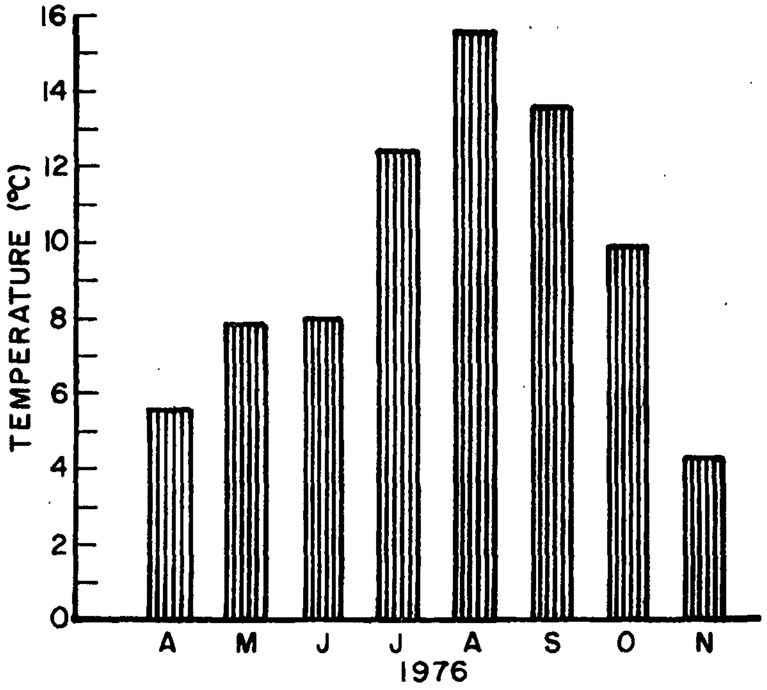

Figure 2.1. Monthly mean temperatures measured in Lake Michigan near Kewaunee Nuclear Power Plant, April-November 1976.

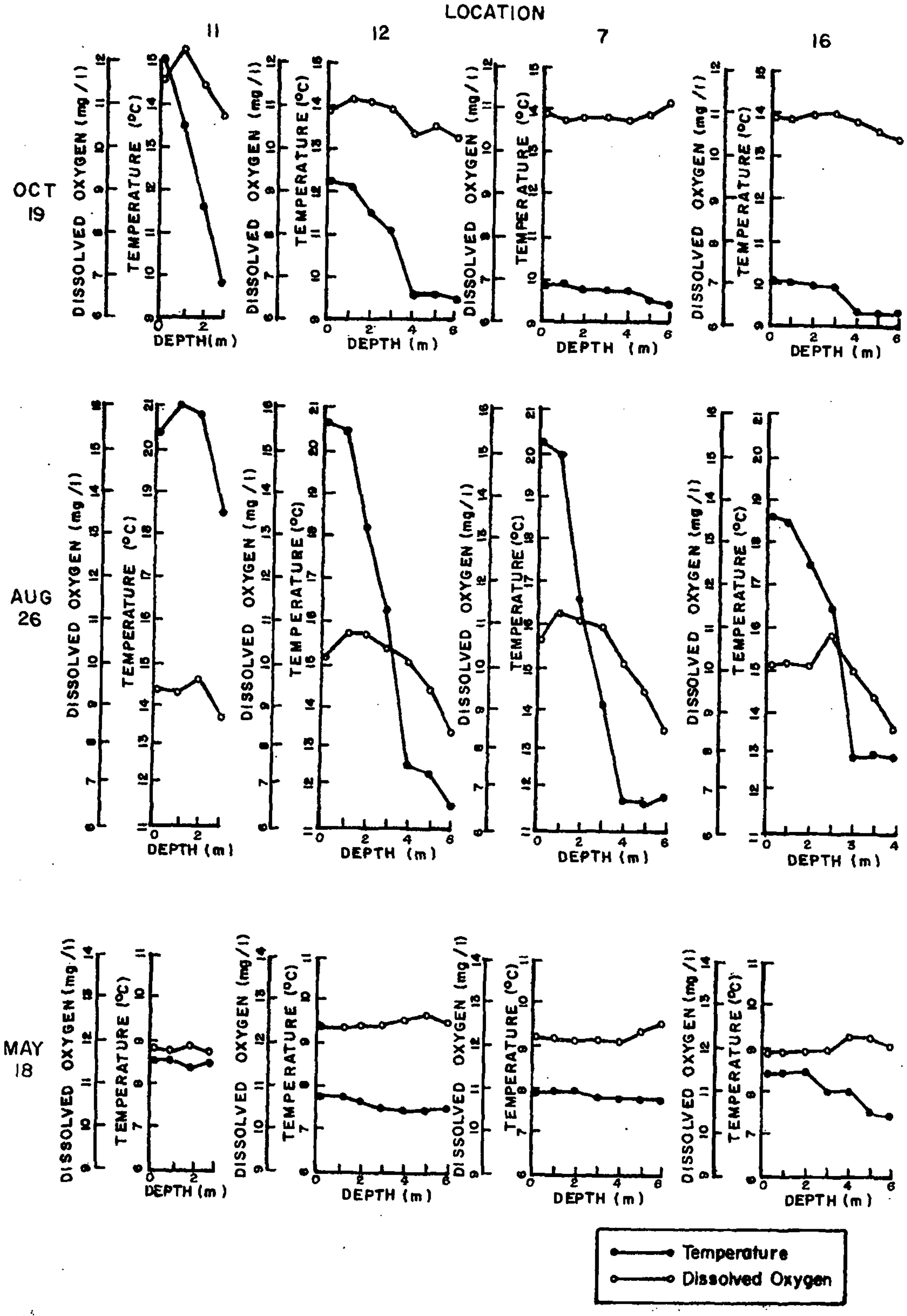

Figure 2.2. Seasonal variability of temperature and dissolved oxygen with depth at the location closest to Kewaunee Nuclear Power Plant (11) and at the three locations along the 20-ft depth contour (7, 12, 16), May, August and October 1976.

April (12.5 mg/l), May (12.2 mg/l), June (12.0 mg/l) and November (12.4 mg/l) were related to the spring and autumn lake overturns. The lowest D.O. concentrations were observed in August and September, when the minimum concentration was 8.2 mg/l.

Dissolved oxygen concentrations generally decreased with depth. However, during periods of significant temperature stratification (July and August), zones of higher D.O. concentrations were frequently observed well below the surface along the thermocline The most pronounced zone of high D.O. concentrations was detected offshore on 24 August, thus coinciding with the maximum thermocline intensity observed during the study period (Figure 2.2). The maximum oxygen values were likely due to extension of the light compensation point into the hypolimnion, which makes photosynthetic oxygen generation possible in this region (Hutchinson 1957). The density stratification of the metalimnion, which overlies the hypolimnion, prevents vertical migration of the excess oxygen beyond the band of maximum density (and temperature) change. The conditions necessary for the occurrence of this natural phenomenon existed on 24 August. Secchi disc measurements, which are directly related to the compensation depth, showed that the euphotic zone extended to the bottom of the water column throughout the study area. Calculations of the stability of the water column provide an estimate of the vertical resistance to mixing. Stability values in a well-mixed water column are usually 0.00000-0.00001 per m; however, the stabilities at almost all locations rose as high as 0.0004 per m to 0.0006 per m in August. The very high stability on 24 August produced a more extreme oxygen maximum zone that of 20 July.

Oxygen saturations did not exhibit marked temporal trends. Monthly means ranged from 94% to 103% of saturation; the mean saturation for the entire study period was 98%. High oxygen saturations were associated with the zones of high dissolved oxygen found in August. The offshore Location 14 showed a saturation of 127% at 2-m depth on 24 August.

3. Nutrients

Nitrate concentrations displayed only slight spatial variations from the annual mean of 0.17 mg/l-N. Temporal variations were also small; monthly means ranged from 0.13 to 0.19 mg/l-N.

Highest nitrite concentrations were observed in August and September (0.0027 and 0.0032 mg/l-N, respectively). The summer high was probably related to biological activities.

Total organic nitrogen concentrations generally varied little from the annual mean of 0.23 mg/l. Monthly means ranged from 0.22 to 0.29 mg/l between April and October, then fell to 0.13 mg/l in November.

Ammonia and soluble orthophosphate concentrations were usually at or below their respective analytical detection limits of 0.01 mg/l-N and 0.001 mg/l-P. Soluble orthophosphate monthly means were as high as 0.001 mg/l-P only in August; this was probably due to biological activity.

Total phosphorus concentrations were higher at near-shore locations than at mid-shore and offshore locations (Appendix 2-B, Table 4). Near shore turbulence produced resuspension of bottom sediments, which are enriched in phosphorus relative to Lake Michiga waters (Schleicher and Kuhn 1970). This effect was more pronounced in April (mean of 0.025 mg/l-P) than in the other months (means of 0.002 to 0.020 mg/l-P). It was also observed in June and July at the location closest to the KNPP discharge, and was related to greater turbulence in this area caused by the underwater promontory extending lakeward from KNPP.

Soluble silica concentrations were higher at offshore locations than nearshore, and also usually increased with depth. Temporal variations were more extreme than spatial ones, with monthl means ranging from 0.13 to 0.78 mg/l-SiO_2. No obvious relationship with diatom populations could be discerned.

4. pH

The pH generally varied little from the annual mean of 8.2. However, at Locations 4, 8, 12, 13 and 14 zones of high pH were observed in conjunction with the bands of high dissolved oxygen mentioned previously (Appendix 2-C). The mechanism increasing pH in August was photosynthesis which lowered carbon dioxide concentrations near the thermocline (Hutchinson 1957).

5. Major Anions and Cations

Calcium was close to the annual mean of 35 mg/l in every month, but was slightly higher at the inshore locations.

Magnesium concentrations varied little, either spatially or temporally, from the mean of 11.6 mg/l.

Total hardness concentrations are calculated from those of calcium and magnesium and therefore showed little variation from the annual mean of 134 mg/l-$CaCO_3$.

Potassium, chloride, fluoride, sodium and sulfate varied only slightly from their respective annual means of 1.1 mg/l, 8.1 mg/l, 0.10 mg/l, 4.3 mg/l and 21 mg/l.

Total alkalinity concentrations varied little temporally from the annual mean of 105 mg/l-$CaCO_3$, but concentrations were slightly higher inshore than offshore, particulary in April.

6. Turbidity, Residues, Specific Conductance and True Color

Turbidity was generally low with an annual mean of 4.0 N.T.U. The only turbidity values exceeding 10 N.T.U. were measured on 27 April at all three inshore locations and on 15 June and 20 July in front of the discharge at the 10 ft depth contour. April was the most turbulent month of the study period, and high turbidity values are a common natural feature of this area during periods of high turbulence (Ellis 1975). Turbidity decreased with distance from shore due to the lower turbulence at greater water depths; however, this effect was smaller during the present study than in most previous years (Ellis 1975).

Nonfiltrable residues (total suspended solids) had a yearly mean of 6 mg/l and behaved similarly to turbidity in that concentrations decreased with distance from shore and that this spatial trend was less obvious than in previous years.

Filtrable residues (total dissolved solids) did not vary significantly either temporally or spatially from the annual mean of 166 mg/l. The major anions and cations, which compose total dissolved solids, similarly displayed this lack of variation. Specific conductance also varied little either temporally or spatially; the annual mean was 280 μmhos/cm (at 25 C).

Dissolved solids were directly related to specific conductance values by the formula:

$$KA = S$$

where K is specific conductance, S is dissolved solids and A is a conversion factor which usually ranges from 0.55 to 0.75 (Hem 1970). Insertion of the monthly means of dissolved solids (153 to 184 mg/l) and specific conductance (270 to 300 μmhos/cm at 25 C) yielded a range of A's from 0.56 to 0.64. These values are typical of waters with low sulfate concentrations (Hem 1970).

Total residue (total solids) concentrations, the sum of nonfiltrable and filtrable residues, showed no significant variations from the annual mean of 172 mg/l.

True color was close to the mean of 2 units throughou this study period.

7. Bacteria

Total coliform bacteria counts were slightly higher than in past study periods, with an overall mean of 18 organisms per 100 ml. Counts in April, July, and September were noticably higher than in other months.

Fecal coliform bacteria displayed very low densities in every month but July, which had a mean of 72 organisms per 100 ml The major cause of this was very high densities at the location closest to KNPP (590 and 630 organisms per 100 ml). The probable reason for those densities was runoff into Lake Michigan from sewage sludge which had been applied to surface land in the vicinity on the day preceding sampling. The other months had mean densities of 0-2 organisms per 100 ml.

The yearly mean for fecal streptococci was 1 organism per 100 ml. The ratio of fecal coliform to fecal streptococci bacteria in every month but July indicated that the source of these bacteria was most probably poultry or livestock wastes (Geldreich and Kenner 1969). During July this ratio suggested human wastes throughout the study area, and was related to the land application of sewage sludge.

The annual mean for standard plate count bacteria at 20.0 C was 17000 orgainsms per 100 ml. Standard plate count bacteria densities were noticeably greater in April and July, which were months in which total coliforms were also higher.

8. Biochemical Oxygen Demand, Chemical Oxygen Demand and Total Organic Carbon

The low biochemical oxygen demand (B.O.D.), chemical oxygen demand (C.O.D.) and total organic carbon (T.O.C.) in the study area indicated a very light load of materials that could cause oxygen depletions.

The annual mean of B.O.D. was 1.0 mg/l. B.O.D. concentrations displayed no spatial or temporal trends of significance and did not exceed 2.9 mg/l.

The yearly C.O.D. mean for all locations was 7.2 mg/l. C.O.D. concentrations were somewhat more variable than thos of B.O.D., but no significant trends were observed.

T.O.C. concentrations deviated only slightly from the annual mean of 2.5 mg/l.

9. Indicators of Industrial Contamination

Hydrazine concentrations were below the analytical detection limit of 0.004 mg/l during the 1976 study period.

10. Trace Metals

The annual means for total iron and manganese were 79 μg/l and 3.3 μg/l, respectively. Concentrations decreased with distance from shore (increasing depths) (Appendix 2-B). This spatial trend was caused by nearshore turbulence which produced resuspension of iron and manganese enriched sediments. This pattern has been more influential in other years (Ellis 1975) since less turbulence was observed on 1976 sampling dates. The April monthly means for both metals were notably higher than those of the other months, probably because bottom material resuspended during winter storms was still present in the water column during the early part of the study period, and also because of April turbulence.

During June and July concentrations of both metals were higher at Location 11 in front of the KNPP discharge as were turbidities and total phosphorus concentrations. This was caused by the greater turbulence associated with the promontory, and has been noted previously (Ellis 1975, 1976).

The annual mean for soluble iron was 4 μg/l and concentrations varied little spatially. Soluble iron constituted approximately 5% of the iron measured throughout the study period;

this percentage was lower at 10 ft locations and higher at 40 ft locations.

Zinc displayed relatively wide, nonsystematic fluctuations from its annual mean of 8 μg/l (range of 5 to 240 μg/l); total chromium and copper showed much less variation from their respective means of 1.0 μg/l and 1.7 μg/l. There was a slight tendency toward higher concentrations at nearshore locations. This trend was much less pronounced than that observed for total iron and manganese.

Arsenic, boron, cadium, lead and nickel were usually near or below their analytical detection limits throughout the study period and no particular trends were observed. Arsenic concentrations did not exceed 3 μg/l and were often below the analytical detection limit of 1 μg/l; the annual mean was 1 μg/l. Boron concentrations varied little from the yearly mean of 30 μg/l. Cadmium was generally below the analytical detection limit of 0.02 μg/l, although higher concentrations were observed scattered randomly throughout the study area in various months. Lead and nickel concentrations very seldom exceeded the analytical detection limit of 1 μg/l.

Mercury concentrations were usually close to or below the annual mean of 0.21 μg/l. However, in June a series of very high concentrations (0.78 - 3.6 μg/l) were determined. There is a strong possibility that these values were caused by contamination of a sampler, since all of the questionable values were found in the "A" replicates. One August concentration (8.9 μg/l) was also much higher than usual for the study area.

C. Statistical Analysis of Chemical Data

The results of the one-way analysis of variance performed on all parameters strongly indicated that water quality in the immediate discharge area of KNPP (Location 11) was not significantly different from that in control areas at the same depth contour but well outside of the immediate discharge area (Locations 2 and 20). Oxygen saturation was the only one of the 46 parameters measured during this study that varied significantly between the two areas. The mean saturation in the immediate discharge area was 104%, while in the reference areas the mean was 98%. The closeness of both saturations to 100% indicated that this statistical difference was not environmentally significant.

D. Comparison of 1976 Data to the Data of Previous Years

The yearly means, minimums and maximums compiled from all lake sampling locations for each parameter measured during the 1973, 1974, 1975 and 1976 study periods are presented in Tables 2.9 through 2.12. Comparison of the means shows that between 1975 and 1976 the values for 24 parameters increased, 10 decreased and 13 remained unchanged. The variations in yearly means were generally smaller in magnitude than the normal temporal or spatial variations measured in Lake Michigan (Gara and Hawley 1974, Ellis 1975, 1976) and, therefore, need not be discussed. Some of the constituents that did show the greatest year to year variations are, however, discussed below.

Water temperatures were notably higher in 1976 than in 1975. This increase was caused by a return to more normal June

Table 2.9. Yearly means, minimums and maximums for selected general water quality parameters and the aquatic nutrients from Lake Michigan near the Kewaunee Nuclear Power Plant in 1973, 1974, 1975 and 1976.

Parameter		Study Period			
		1973	1974	1975	1976
Temperature (°C)	mean	10.2	9.8	8.2	9.6
	min-max	1.8-18.8	2.3-16.6	3.3-17.8	3.6-20.8
Oxygen, dissolved (mg/l)	mean	10.5	11.1	11.1	11.2
	min-max	6.9-13.2	9.2-13.5	8.7-13.3	9.0-13.2
Oxygen, saturation (%)	mean	94	97	94	98
	min-max	63-115	80-111	73-110	75-124
pH	mean	8.2	8.3	8.1	8.2
	min-max	7.6-8.4	7.9-8.7	7.5-8.5	8.0-8.6
Alkalinity, total (mg/l-$CaCO_3$)	mean	109	107	106	105
	min-max	102-135	93-120	100-117	101-117
Nitrate (mg/l-N)	mean	0.15	0.15	0.20	0.17
	min-max	0.02-0.29	0.02-0.43	0.04-0.38	0.12-0.31
Nitrite (mg/l-N)	mean	0.0026	0.0026	0.0024	0.0021
	min-max	0.0006-0.0060	<0.0001-0.011	0.0007-0.012	<0.0001-0.0098
Ammonia (mg/l-N)	mean	0.01	0.01	0.01	0.01
	min-max	<0.01-0.03	<0.01-0.07	<0.01-0.06	<0.01-0.04
Organic nitrogen, total (mg/l)	mean	0.25	0.23	0.20	0.23
	min-max	0.10-0.73	0.09-0.50	0.11-0.37	0.09-0.51
Phosphorus, total (mg/l-P)	mean	0.013	0.014	0.009	0.014
	min-max	0.002-0.063	0.004-0.12	0.003-0.046	0.001-0.098
Orthophosphate, soluble (mg/l-P)	mean	0.001	<0.001	<0.001	<0.001
	min-max	<0.001-0.004	<0.001-0.004	<0.001-0.008	<0.001-0.004
Silica, soluble (mg/l-SiO_2)	mean	0.52	0.45	0.87	0.49
	min-max	0.11-1.4	0.09-0.92	0.26-1.5	0.04-1.0

Table 2.10. Yearly means, minimums and maximums for major cations and anions and other general water quality parameters from Lake Michigan near the Kewaunee Nuclear Power Plant in 1973, 1974, 1975 and 1976.

Parameter		Study Period			
		1973	1974	1975	1976
Calcium (mg/l)	mean	35	34	35	35
	min-max	29-41	30-48	32-40	31-41
Magnesium (mg/l)	mean	11.2	11.2	11.5	11.6
	min-max	9.5-14.0	10.6-16.8	10.9-14.5	10.8-15.0
Hardness, total (mg/l-$CaCO_3$)	mean	133	132	135	134
	min-max	111-161	121-189	126-161	123-163
Potassium (mg/l)	mean	1.2	1.1	1.1	1.1
	min-max	1.0-2.0	0.9-1.6	1.0-1.4	1.0-1.8
Chloride (mg/l)	mean	8.0	7.7	7.8	8.1
	min-max	7.0-15.5	5.0-10.5	6.0-9.9	7.5-9.8
Fluoride (mg/l)	mean	0.11	0.10	0.10	0.10
	min-max	0.09-0.16	0.08-0.14	0.09-0.12	0.09-0.11
Sodium (mg/l)	mean	4.5	4.4	4.3	4.3
	min-max	4.2-4.8	4.1-5.2	4.1-4.6	4.2-4.8
Sulfate (mg/l)	mean	19	19	19	21
	min-max	14-23	15-28	9-25	18-30
Turbidity[a] (N.T.U.)	mean	7	6	1.9	4.0
	min-max	1-44	<1-83	0.3-30	0.5-42
Residue, nonfiltrable (mg/l)	mean	7	10	4	6
	min-max	<1-55	<1-124	<1-33	<1-64
Residue, filtrable (mg/l)	mean	164	167	159	166
	min-max	134-196	134-228	132-188	134-201
Residue, total (mg/l)	mean	171	176	163	172
	min-max	136-235	142-296	134-208	136-248
Conductance, specific (µmhos/cm)	mean	274	280	280	280
	min-max	258-290	270-300	250-300	270-320
Color, true (units)	mean	2	3	2	2
	min-max	1-6	1-10	<1-5	<1-8

[a] Analytical detection limit change between 1974 and 1975.

Table 2.11. Yearly means, minimums and maximums for indicators of industrial and municipal contamination from Lake Michigan near the Kewaunee Nuclear Power Plant in 1973, 1974, 1975 and 1976.

		Study Period			
Parameter		1973	1974	1975	1976
Biochemical oxygen demand (5 day) (mg/l)	mean	1.8	1.2	1.6	1.0
	min-max	0.5-3.5	<0.5-3.4	<0.5-3.7	<0.5-2.9
Chemical oxygen demand (mg/l)	mean	6.8	5.1	7.1	7.2
	min-max	1.5-12	1.3-13	3.9-12	2.5-12
Organic carbon, total[a] (mg/l)	mean	8	5	3	2.5
	min-max	1-24	2-9	1-9	1.0-4.8
Bacteria, total coliform (No./100 ml)	mean	8	8	3	20
	min-max	0-4300	0-200	0-130	0-120
Bacteria, fecal coliform (No./100 ml)	mean	1	1	1	14
	min-max	0-20	0-12	0-6	0-630
Bacteria, fecal streptococci (No./100 ml)	mean	2	2	19	2
	min-max	0-47	0-22	0-970	0-29
Bacteria, standard plate count (20.0 C)	mean	30000	9900	14000	17000
	min-max	490-6,900,000	100-200,000	75-250,000	75-450,000
Hydrazine (mg/l)	mean	<0.004	<0.004	<0.004	<0.004
	min-max	<0.004-0.004	<0.004-<0.004	<0.004-<0.004	<0.004-<0.004

[a] Method and analytical detection limit change between 1975 and 1976.

[b] Not determined in 1973.

Table 2.12. Yearly means, minimums and maximums for trace metals from Lake Michigan near the Kewaunee Nuclear Power Plant in 1973, 1974, 1975 and 1976.

		Study Period			
Parameter		1973	1974	1975	1976
Arsenic	mean	1	<1	1	1
(μg/l)	min-max	<1-4	<1-4	<1-3	<1-3
Boron	mean	30	30	30	30
(μg/l)	min-max	10-120	<10-150	<10-170	<10-80
Cadmium[a]	mean	0.1	0.05	0.02	0.07
(μg/l)	min-max	<0.1-1.6	<0.02-0.38	<0.02-0.58	<0.02-1.6
Chromium, total[a]	mean	2	1.0	0.8	1.0
(μg/l)	min-max	1-7	<0.1-5.8	0.1-3.7	<0.1-4.1
Copper	mean	1.4	1.9	0.9	1.7
(μg/l)	min-max	0.1-4.9	0.8-9.2	<0.1-5.8	0.5-12
Iron, total	mean	93	140	38	79
(μg/l)	min-max	2-950	5-1600	2-300	2-710
Iron, soluble	mean	–[b]	–[b]	9	4
(μg/l)	min-max			<1-80	<1-32
Lead	mean	5	1	<1	3
(μg/l)	min-max	<1-120	<1-16	<1-7	<1-26
Manganese[a]	mean	4	4	1.7	3.3
(μg/l)	min-max	1-17	0.6-49	0.1-52	0.3-28
Mercury	mean	0.09	0.09	0.12	0.21
(μg/l)	min-max	<0.05-2.9	<0.05-0.89	<0.05-0.32	<0.05-8.9
Nickel	mean	1	2	<1	<1
(μg/l)	min-max	<1-3	<1-29	<1-3	<1-6
Zinc[a]	mean	13	10	8.5	8.0
(μg/l)	min-max	1-86	0.1-62	0.4-50	0.5-240

[a] Method and analytical detection limit change between 1973 and 1974.

[b] Not determined in 1973 and 1974.

and July temperatures on the 1976 sampling dates. It is very doubtful that true changes in lake Michigan temperatures have been occurring.

Turbidity, nonfiltrable residue, total iron, manganese and total phosphorus were all noticeably higher in 1976 than in 1975. Nearshore turbulence was more pronounced on several 1976 sampling dates compared to 1975. Therefore, these turbulence-related parameters all showed increases in their annual means, although only phosphorus was as high as in 1973 or 1974.

Soluble silica concentrations were lower in 1976 than in 1975, but were quite close to those of 1973 and 1974. In the context of the 1973 - 1976 period, the 1975 levels appeared to be unusually high.

Fecal streptococcus bacteria were lower and total and fecal coliform bacteria were higher in 1976 than in 1975. These changes though noticeable, were probably due to random variations plus runoff from the sewage sludge in July (a one-time occurrence), rather than to any long-term change in Lake Michigan water quality.

No changes of significance were noted for the other parameters determined in this study.

Data collected near KNPP have been compared to data from other parts of Lake Michigan and historical trends have been discussed in previous studies for Wisconsin Public Service (Ellis 1975, NALCO Environmental Sciences 1976). This work showed that water quality near KNPP was characteristic of Lake Michigan waters and that the variability present in the waters near KNPP could be accounted for by natural processes. All of the data in the present study are in accordance with these findings.

IV. Summary and Conclusions

1. Water quality in Lake Michigan near the Kewaunee Nuclear Power Plant was in compliance with the standards established by the Wisconsin Department of Natural Resources.

2. Elevated temperatures due to the discharge of KNPP were measured every month of the study period but April and May. These temperature increases were limited to the upper portion of the water column and to locations close to the immediate discharge area of KNPP.

3. Seasonal changes were noted for water temperature, dissolved oxygen, pH, and several nutrients.

4. A thermocline existed at many 30 and 40-ft contour locations in July and August. Increased dissolved oxygen concentrations and pH's occurred along the thermocline in conjunction with the regions of greatest temperature decrease with depth.

5. The concentrations of some of the aquatic nutrients were influenced by biological activity during the summer.

6. The major anions and cations measured displayed little variation.

7. Turbidities and nonfiltrable residues varied less during this study period than in several past years because less weather-related turbulence occurred near the sampling dates.

8. Fecal coliform bacteria densities and fecal streptococci densities were very low except in July, when fecal coliforms were high throughout the study area. The ratio of fecal coliform bacteria to fecal steptococci bacteria was representative of waste runoff from

poultry and livestock, with the exception of July, when the ratio was characteristic of human wastes.

9. Biochemical oxygen demand, chemical oxygen demand and total organic carbon values exhibited slight variations and indicated little or no organic pollution in Lake Michigan near KNPP.

10. Chlorine and hydrazine were not detected in Lake Michigan waters near KNPP during the 1976 study period.

11. Total iron and manganese concentrations decreased with distance from shore because of the reduced turbulence in deeper waters. The other trace metals, with the exception of a few mercury values, displayed only minor variations; the concentrations of many metals were near or below their analytical detection limits.

12. Comparison of spatial means indicated that Lake Michigan waters near KNPP were generally homogeneous. Statistical evaluation of data showed that few parameters were significantly different in front of the KNPP discharge from control areas along the same depth contour. The one difference which was observed was environmentally insignificant.

13. The differences in water quality between this study and previous studies were generally minor in comparison to the natural spatial and temporal variations found in Lake Michigan.

14. Operation of KNPP had no effect on the water quality of Lake Michigan with the exception of slightly elevated water temperature close to the Plant's discharge.

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Chapter 3

PHYTOPLANKTON

Jose B. Festin

OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR
KEWAUNEE NUCLEAR POWER PLANT

SIXTH ANNUAL REPORT
January - December 1976

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Chapter 3

PHYTOPLANKTON

Jose B. Festin

I. Introduction

This chapter presents a discussion of phytoplankton data from samples collected in Lake Michigan during 1976 near the Kewaunee Nuclear Power Plant (KNPP). This study was conducted during the third year of operation of KNPP and is part of a long-term monitoring program to assess any effects KNPP may have on phytoplankton populations in Lake Michigan.

The specific objectives of the study were:

1. to document phytoplankton species composition and abundance;
2. to determine spatial distribution and temporal fluctuations of phytoplankton populations in the site area; and
3. to compare 1976 phytoplankton data with preoperational and 1974-1975 operational data to assess possible effects of Plan operation.

II. Field and Analytical Procedures

Duplicate water samples for phytoplankton analyses were collected monthly, April through November, at seven locations (Figure 3.1). Three locations were along the 10 ft depth contour (inshore Locations 2, 11 and 20), three were along the 20 ft depth contour (middle Locations 7, 12 and 16) and one was along the 40 ft depth contour (offshore Location 14). These locations were also positioned along five east-west transects. Locations 11, 12 and 14 were positioned along Transect III, Location 2 along Transect I and Location 20 along Transect V. Locations 7 and 16 were positioned along Transects II and IV, respectively. The approximate extent of the immediate discharge area was determined by plume mapping in 1974 and 1975 and was found to include Locations 7, 11, 12 and 16 (Lovorn 1975; Williams 1976). However, because of the shifting movement of the thermal plume these locations were found to be only occasionally within the influence of the thermal plume. All other locations were beyond the reach of the thermal plume and considered control locations. Each sample was collected from 1 m below the surface with a non-metallic Van Dorn water sampler, placed in a 1.9 liter polyethylene bottle and preserved at the time of collection by the addition of 60 ml of "M^3" fixative (Meyer 1971). Samples were collected on 27 April, 18 May, 15 June, 20 July, 24 August 22 September, 19 October and 16 November.

The volume of each sample processed for diatom analysis was dependent upon the turbidity and abundance of organisms. Diatoms were cleaned using a concentrated nitric acid/potassium dichromate

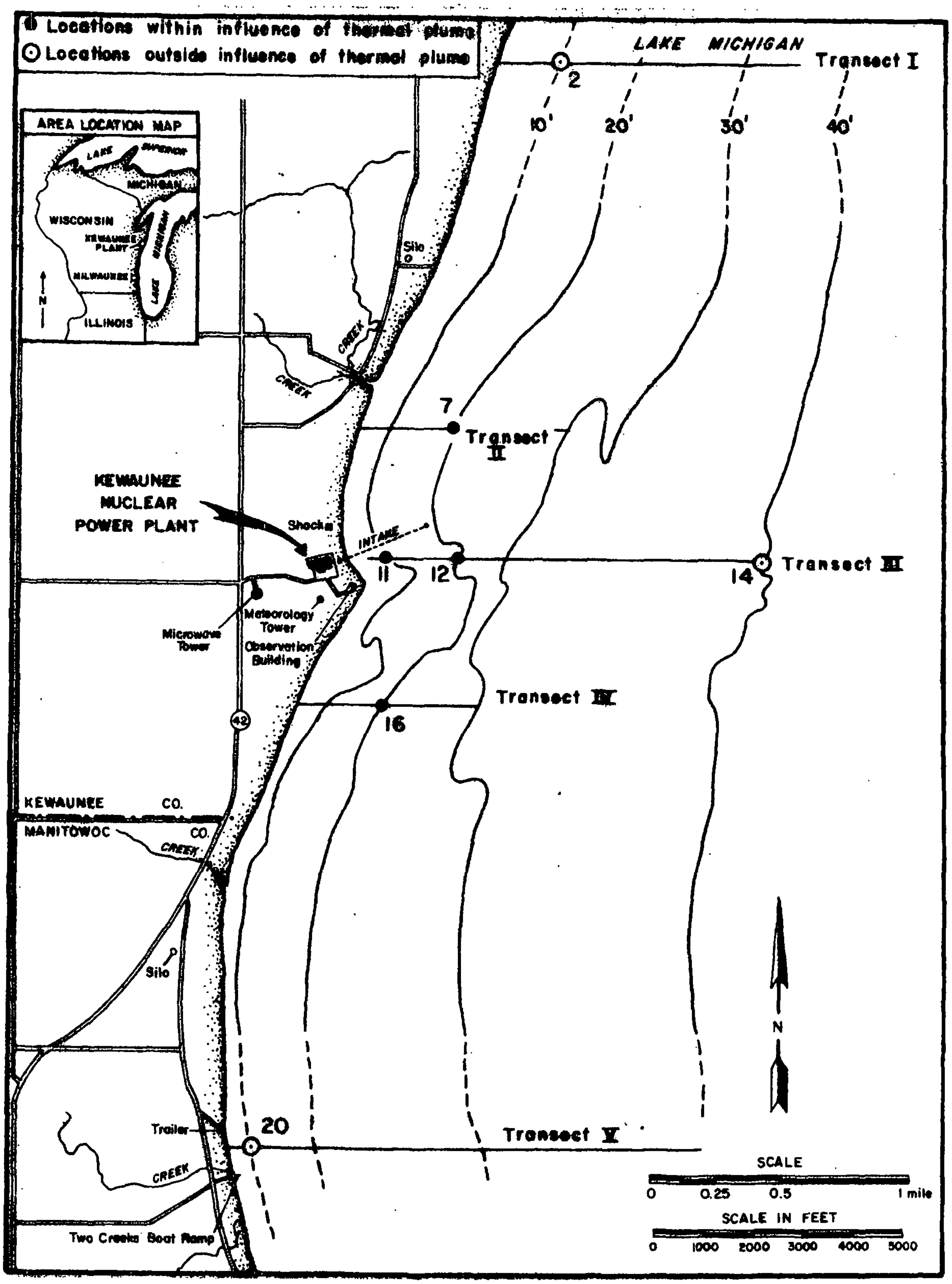


Figure 3.1. Map of phytoplankton sampling locations in Lake Michigan near Kewaunee Nuclear Power Plant during 1976.

treatment (Hohn and Hellerman 1963) and collected on a 0.45 m porosity, 47 mm diameter Millipore filter (Holland 1969). A section of the filter was mounted on a slide, cleared with immersion oil and examined with phase contrast at a maximum of 1250 X magnification. A sufficient quantity (usually 400) of diatom valves was counted to estimate the density of the abundant species.

Phytoplankton other than diatoms were prepared for analysis by processing 875 ml of the preserved water sample. Each subsample was allowed to settle overnight after the addition of 10 ml of liquid detergent (Mackenthun 1969) and then successively condensed to a final 200:1 concentration. An aliquot of the concentrated sample was analyzed in accordance with the Lackey scan technique (Lackey 1938) under bright field or phase contrast at either 400 or 500 X magnification. A sufficient quantity of phytoplankton reporting units were counted to estimate the density of all species

Phytoplankton were recorded as numbers of reporting units per milliliter. A reporting unit consisted of each cell or frustule fo unicellular species; a 100 um length of filament or trichrome for filamentous species; and four cells for each colonial species excep *Aphanocapsa* sp., *Aphanothece* sp. and *Microcystis* sp. which were reported in 50 cell units.

The fragile diatoms *Microsiphona* and *Rhizosolenia*, which disintegrate upon acid cleaning, were enumerated in the non-diatom pre parations.

All organisms were identified to the lowest positive taxon, using appropriate taxonomic keys.

A one-way analysis of variance (ANOVA) was applied to the data collected each month. Prior to analysis, the data were square root transformed to stabilize the variances. Tukey's multiple comparison procedure was used following the ANOVA to isolate specific significant differences among locations along each depth contour (inshore, middle and offshore) and along each of the east-west transects.

Species diversity (Shannon 1948) was calculated using phytoplankton data from each sampling location on a monthly basis. Diversity values provide a numerical expression of community structure. The number of species and the number of individuals of each species in the sample influence the diversity index (H). The species content of the sample is referred to as the "species richness" component of diversity. The distribution of the number of individual's within a species is referred to as "equitability". Equitability or evenness (J) may range from 0.0 to 1.0 and is highest when all species in the sample are present in nearly equal numbers. Species diversity, which may range from 0.0 to some positive number usually less than 4.0, is increased by increasing species richness and increasing evenness.

III. Results and Discussion

A. Phytoplankton Community Composition and Distribution

The phytoplankton collected in Lake Michigan near the KNPP were typical of the algal community in near shore areas of th lake. It included truly floating algae that are familiar in the study site, those introduced from adjacent water masses to the north, south and offshore areas and, more importantly, benthic species that have been scoured from the bottom and incorporated into the plankton.

Two hundred fifty-seven taxa representing 87 genera and seven major algal divisions comprised the phytoplankton (Appendix 3-A). The number of taxa encountered was greater in fall than in spring and summer.

When compared with the 1975 data, 14 genera and 76 specie were found in the taxonomic composition of phytoplankton in 1976; however, eight genera and 51 species not reported in 1975 were identified in 1976. Because these taxa were generally rare, their importance as individual members of the phytoplankton standing cro is not known. Some species were also added or removed from the lis as a result of refinements in taxonomic nomenclature.

Diatoms comprised the most dominant and diverse division throughout the entire study period (Table 3.1; Appendix 3-A). The other major groups of algae were of lesser importance. Eighteen species of diatoms, two species of golden-brown algae, two species of blue-green algae and one cryptophyte species composed the major portion of the phytoplankton and were considered dominant forms.

Table 3.1. Abundance and percent composition of total phytoplankton and major phytoplankton divisions collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April to November 1976.

Sampling Location	Phytoplankton Reporting Units/ml	Bacillariophyta Reporting Units/ml	Bacillariophyta Percent Composition	Chlorophyta Reporting Units/ml	Chlorophyta Percent Composition	Chrysophyta Reporting Units/ml	Chrysophyta Percent Composition	Cyanophyta Reporting Units/ml	Cyanophyta Percent Composition	Cryptophyta Reporting Units/ml	Cryptophyta Percent Composition
27 April											
Inshore											
2	11554	11408	98.7	53	0.5	66	0.6	27	0.2	<1	0.0
11	5861	5740	98.0	33	0.6	77	1.3	10	0.2	0	0.0
20	6957	6811	97.9	42	0.6	70	1.0	33	0.5	0	0.0
Mean	8124	7936	98.2	43	0.6	71	1.0	23	0.3	0	0.0
Middle											
7	5327	5199	97.6	60	1.1	56	1.0	12	0.2	0	0.0
12	3948	3839	97.2	26	0.7	72	1.8	11	0.3	0	0.0
16	4286	4190	97.8	29	0.7	55	1.3	12	0.3	0	0.0
Mean	4520	4409	97.5	38	0.8	61	1.4	12	0.3	0	0.0
Offshore											
14	2851	2748	96.4	36	1.2	55	1.9	12	0.4	0	0.0
Mean	2851	2748	96.4	36	1.2	55	1.9	12	0.4	0	0.0
Total Mean	5165	5031	97.4	39	0.9	62	1.4	16	0.3	0	0.0
18 May											
Inshore											
2	2546	2454	96.4	49	1.9	27	1.1	16	0.6	0	0
11	2544	2472	97.2	31	1.2	21	0.8	20	0.8	0	0
20	3025	2970	98.2	27	0.9	14	0.4	15	0.5	0	0
Mean	2705	2632	97.3	36	1.3	21	0.8	17	0.6	0	0
Middle											
7	1809	1731	95.7	23	1.3	23	1.3	31	1.7	0	0
12	1556	1492	95.9	22	1.4	17	1.1	25	1.6	0	0
16	2428	2373	97.7	37	1.5	8	0.3	11	0.4	0	0
Mean	1931	1865	96.4	27	1.4	16	0.9	22	1.2	0	0
Offshore											
14	1355	1295	95.6	15	1.1	21	1.5	24	1.8	0	0
Mean	1355	1295	95.6	15	1.1	21	1.5	24	1.8	0	0
Total Mean	1997	1931	96.4	26	1.3	19	1.1	21	1.2	0	0

Table 3.1. (continued)

Sampling Location	Phytoplankton	Bacillariophyta		Chlorophyta		Chrysophyta		Cyanophyta		Cryptophyta	
	Reporting Units/ml	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition
15 June											
Inshore											
2	7144	6990	97.8	47	0.7	76	1.1	29	0.4	<1	0.0
11	11267	11113	98.6	54	0.5	58	0.5	41	0.4	2	0.0
20	4452	4345	97.6	32	0.7	58	1.3	16	0.4	0	0.0
Mean	7621	7483	98.0	44	0.6	64	1.0	29	0.4	2	0.0
Middle											
7	3237	3159	97.6	23	0.7	30	0.9	24	0.7	0	0.0
12	2069	1959	94.7	29	1.4	50	2.4	30	1.4	0	0.0
16	2002	1898	94.8	27	1.4	24	1.2	52	2.6	0	0.0
Mean	2436	2339	95.7	26	1.2	35	1.5	35	1.6	0	0.0
Offshore											
14	1204	1123	93.3	31	2.6	33	2.8	16	1.4	0	0.0
Mean	1204	1123	93.3	31	2.6	33	2.8	16	1.4	0	0.0
Total Mean	3754	3648	95.7	34	1.5	44	1.8	27	1.1	1	0.0
20 July											
Inshore											
2	6801	6588	96.9	38	0.6	65	1.0	109	1.6	0	0.0
11	12505	11709	97.4	88	0.7	87	0.7	134	1.1	5	0.1
20	3123	2974	95.2	16	0.5	123	3.9	9	0.3	0	0.0
Mean	7476	7090	96.5	47	0.6	92	1.9	84	1.0	2	0.0
Middle											
7	4254	4056	95.3	12	0.3	74	1.7	110	2.6	1	0.0
12	3842	3673	95.6	28	0.7	75	2.0	63	1.6	1	0.0
16	2551	2330	91.3	26	1.0	86	3.4	108	4.2	0	0.0
Mean	3549	3353	94.1	22	0.7	78	2.4	94	2.8	1	0.0
Offshore											
14	1687	1597	94.7	7	0.4	61	3.6	19	1.1	1	0.1
Mean	1687	1597	97.7	7	0.4	61	3.6	19	1.1	1	0.1
Total Mean	4237	4013	96.1	25	0.6	77	2.6	66	1.6	1	0.0

Table 3.1. (continued)

Sampling Location	Phytoplankton	Bacillariophyta		Chlorophyta		Chrysophyta		Cyanophyta		Cryptophyta	
	Reporting Units/ml	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition
24 August											
Inshore											
2	1530	1444	94.4	5	0.3	38	2.5	43	2.8	<1	0.0
11	2465	2389	96.9	22	0.9	6	0.3	47	1.9	<1	0.0
20	955	905	94.7	6	0.6	3	0.3	41	4.3	0	0.0
Mean	1650	1579	95.3	11	0.6	16	1.0	44	3.0		
Middle											
7	1616	1541	95.3	13	0.8	10	0.6	50	3.1	<1	0.0
12	1575	1506	95.6	12	0.8	9	0.5	48	3.0	0	0.0
16	825	755	91.5	6	0.8	13	1.5	51	6.2	0	0.0
Mean	1339	1267	94.1	10	0.8	11	0.9	50	4.1		
Offshore											
14	568	508	89.5	5	0.8	24	4.2	30	5.3	<1	0.1
Mean	568	508	89.5	5	0.8	24	4.2	30	5.3	<1	0.1
Total Mean	1186	1118	93.0	9	0.7	17	2.0	41	4.1	<1	0.0
22 September											
Inshore											
2	1299	941	72.4	16	1.2	102	7.8	180	13.9	59	4.5
11	1964	1517	77.2	57	2.9	207	10.6	140	7.1	41	2.1
20	1830	1511	82.6	34	1.9	109	6.0	128	7.0	48	2.6
Mean	1698	1323	77.4	36	2.0	139	8.1	149	9.3	49	3.1
Middle											
7	1006	731	72.7	21	2.1	33	3.2	184	18.3	35	3.5
12	1785	1410	79.0	28	1.6	74	4.1	227	12.7	46	2.6
16	1459	763	52.3	17	1.1	181	12.4	431	29.5	64	4.4
Mean	1417	968	68.0	22	1.6	96	6.6	281	20.2	48	3.5
Offshore											
14	697	265	38.0	6	0.9	72	10.4	288	41.3	64	9.2
Mean	697	265	38.0	6	0.9	72	10.4	288	41.3	64	9.2
Total Mean	1271	852	61.1	21	1.5	102	8.4	239	23.6	54	5.3

Table 3.1. (continued)

Sampling Location	Phytoplankton	Bacillariophyta		Chlorophyta		Chrysophyta		Cyanophyta		Cryptophyta	
	Reporting Units/ml	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition	Reporting Units/ml	Percent Composition
19 October											
Inshore											
2	1562	1352	86.6	20	1.3	10	0.6	121	7.8	57	3.6
11	3113	2907	93.4	13	0.4	9	0.3	134	4.3	49	1.6
20	2319	2012	86.7	10	0.4	42	1.8	226	9.8	29	1.3
Mean	2331	2090	88.9	14	0.7	20	0.9	160	7.3	45	2.2
Middle											
7	948	873	92.0	7	0.7	3	0.3	21	2.2	44	4.6
12	1043	876	84.0	16	1.5	9	0.9	86	8.2	56	5.4
16	1142	952	83.4	10	0.9	12	1.0	121	10.6	46	4.1
Mean	1044	900	86.5	11	1.0	8	0.7	76	7.0	49	4.7
Offshore											
14	422	276	65.4	9	2.1	20	4.6	81	19.2	37	8.7
Mean	422	276	65.4	9	2.1	20	4.6	81	19.2	37	8.7
Total Mean	1266	1089	80.3	11	1.3	16	2.1	106	11.2	44	5.2
16 November											
Inshore											
2	1060	797	75.3	9	0.8	92	8.7	124	11.7	38	3.5
11	1291	1047	81.1	14	1.1	147	11.4	39	3.0	43	3.3
20	1025	790	77.0	11	1.0	136	13.2	42	4.1	47	4.6
Mean	1125	878	77.8	11	1.0	125	11.1	68	6.3	43	3.8
Middle											
7	880	670	76.1	10	1.1	124	14.0	47	5.3	30	3.4
12	998	707	70.8	9	0.9	170	17.0	72	7.3	40	4.0
16	674	527	78.2	8	1.2	73	10.9	30	4.4	35	5.3
Mean	851	635	75.0	9	1.1	122	14.0	50	5.7	35	4.2
Offshore											
14	591	504	85.2	5	0.9	14	2.4	20	3.5	47	8.0
Mean	591	504	85.2	5	0.9	14	2.4	20	3.5	47	8.0
Total Mean	856	672	79.3	8	1.0	87	9.2	46	5.2	42	5.3
Yearly Mean	2466	2294	87.4	22	1.0	53	3.6	70	6.0	18	2.0

Each dominant taxon constituted 5% or more of the phytoplankton at one location during one or more collection periods (Table 3.2). Over one half of the dominant species were abundant for only one to three months, and only six species, all diatoms, appeared as dominants in four or more of the eight months of sampling. These species were also dominant in the KNPP area during the preoperational period and the first and second year of Plant operation (Table 3.3). Most of these species have also been reported as major components of the phytoplankton community in other areas of western and southwestern Lake Michigan during the past four years (Industrial BIO-TEST Laboratories, Inc. 1973, 1974; Mayhew 1974a, 1974b; Mayhew and Barber 1974; Barber and Redmond 1975, 1976). Density and distribution of the taxa will be described in later sections.

The phytoplankton population exhibited a bimodal seasonal distribution (Figure 3.2). The spring phytoplankton pulse occurred in April and a slightly smaller summer pulse occurred in July. As in previous years the phytoplankton maxima were of a greater magnitude in the inshore area where diatoms were most abundant. Mean monthly populations were largest in April (5165 reporting units/ml), decreased sharply in May and showed a subsequent increase through June and July to produce the summer pulse. In August the phytoplankton populations decreased sharply, generally leveled off through September and October and then decreased slightly to its lowest level (856 reporting units/ml) in November. Seasonal fluctuations of phytoplankton populations in 1976 followed the trend

Table 3.2. Dominant species which composed 5% or more of the total phytoplankton at any location near the Kewaunee Nuclear Power Plant during 1976.

	Months							
Taxa	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Bacillariophyta								
Centrales								
Cyclotella kutzingiana var. *radiosa*				X		X	X	X
Cyclotella michiganiana				X				
Cyclotella stelligera			X		X			
Melosira italica			X					
Stephanodiscus minutus	X							
Stephanodiscus invisitatus		X						
Stephanodiscus sp.		X	X					
Pennales								
Achnanthes linearis						X		
Achnanthes minutissima						X		
Asterionella formosa	X				X		X	X
Cymbella microcephala							X	
Diatoma tenue var. *elongatum*	X	X						
Fragilaria crotonensis	X	X	X	X	X	X	X	X
Fragilaria intermedia	X							
Fragilaria pinnata	X	X	X	X	X	X	X	X
Fragilaria vaucheriae	X			X	X	X		X
Synedra filiformis		X						
Tabellaria flocculosa	X	X	X	X				
Chrysophyta								
Dinobryon divergens						X		X
Dinobryon sociale						X		X
Cyanophyta								
Non-filamentous								
Aphanothece nidulans						X		
Coelosphaerium naegelianum						X	X	X
Cryptophyta								
Rhodomonas minuta var. *nannoplanctica*						X	X	X
Dominant species per month	8	7	6	6	5	11	7	9

Table 3.3. Dominant phytoplankton species which composed 5% or more of the total phytoplankton at any location near the Kewaunee Nuclear Power Plant 1971 - 1976. Numbers indicate last digit of year during which the species was dominant.

Taxa	Months Apr	 May	 Jun	 Jul	 Aug	 Sep	 Oct	 Nov
Bacillariophyta	1^a2^a		1^a2^a	1^a2^a		1^a	1^a2^a	
Centrales								
Cyclotella comta					1,5		5	5
Cyclotella glomerata				3		3	3	
Cyclotella kutzingiana var. *radiosa*				6		6	6	6
Cyclotella michiganiana				6				
Cyclotella ocellata				4		5	3	
Cyclotella stelligera^b	3,4,5	2,5	3,5,6	3,4,5	3,6	5		4
Cyclotella sp.								2
Melosira islandica		3			2			
Melosira italica		3,5	6		2	3,4	3,4	
Rhizosolenia eriensis		2,3			2			
Rhizosolenia longiseta			3,4					
Stephanodiscus binderanus		3						
Stephanodiscus hantzschii		2						4
Stephanodiscus hantzschii-tenuis		1						
Stephanodiscus invisitatus		2,6						
Stephanodiscus minutus	3,4,5,6	2,5	5			5	5	5
Stephanodiscus tenuis		2						
Stephanodiscus sp. 2		5	5					
Stephanodiscus sp.^{b}	3,5	3,5,6	3,5,6	5		3,4,5	3,4,5	3,4,5
Pennales								
Achnanthes linearis						6		
Achnanthes minutissima						6		
Asterionella formosa^b	6		3,4	3,4	4,6	2,5	3,4,5,6	1,2,3,4,5,6
Cymbella microcephala							6	
Diatoma tenue				3,4				
Diatoma tenue var. *elongatum*	6	1,3,6						
Fragilaria capucina^b		1,4	3,4	3,4,5	4,5	5		5
Fragilaria capucina var. *mesolepta*		3						
Fragilaria crotonensis^b	3,4,5,6	1,2,3,4,5,6	3,4,5,6	3,4,5,6	1,2,3,4,6	2,3,4,5,6	3,4,5,6	1,2,3,4,5,6
Fragilaria intermedia	3,6	4,5			2		4,5	5
Fragilaria pinnata^b	3,4,5,6	1,5,6	4,5,6	3,4,5,6	1,2,4,5,6	2,3,4,5,6	1,2,3,4,5,6	5,6
Fragilaria pinnata var. *intercedens*					2			
Fragilaria vaucheriae^b	4,6		4,5	4,5,6	4,6	4,5	5	6
Navicula sp.					1			
Nitzschia acicularis		3,5	5				5	
Nitzschia palea						4		
Nitzschia sp.^{b}				3,4	4	2,3,4	4	3,4
Synedra acus		1						
Synedra familica	4			4				
Synedra filiformis^b	4,5	2,3,4,5,6	3,4,5	3,5		5	5	5
Tabellaria flocculosa^b	3,4,5,6	1,3,4,5,6	3,4,5,6	3,4,5,6	1,2,4,5	2,4,5	4	1,2,4
Chrysophyta								
Dinobryon cylindricum	3,4,5	5						
Dinobryon divergens			4	3	2	2,6	5	6
Dinobryon sociale		2,3	4	3,4		6		6
Peroniella planctonica					5			

Table 3.3. (continued)

Taxa	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Cyanophyta								
Non-filamentous								
Aphanocapsa delicatissima						4		
Aphanocapsa castagnei					3			
Aphanothece clathrata						5	4	
Aphanothece nidulans					3	4,5,6		
Coelosphaerium naegelianum[b]					3,4,5	2,3,4,5,6	3,4,6	2,3,4,6
Gomphosphaeria lacustris						3		
Gomphosphaeria lacustris var. *compacta*					3			2
Filamentous								
Anabaena flos-aquae						2		
Oscillatoria tenuis					2			
Chlorophyta								
Non-filamentour								
Schizochlamys gelatinosa					5			
Cryptophyta								
Rhodomonas minuta var. *nannoplanctica*		5			5	6	6	3,6

[a] No samples collected in that year.
[b] Dominant in four or more months.

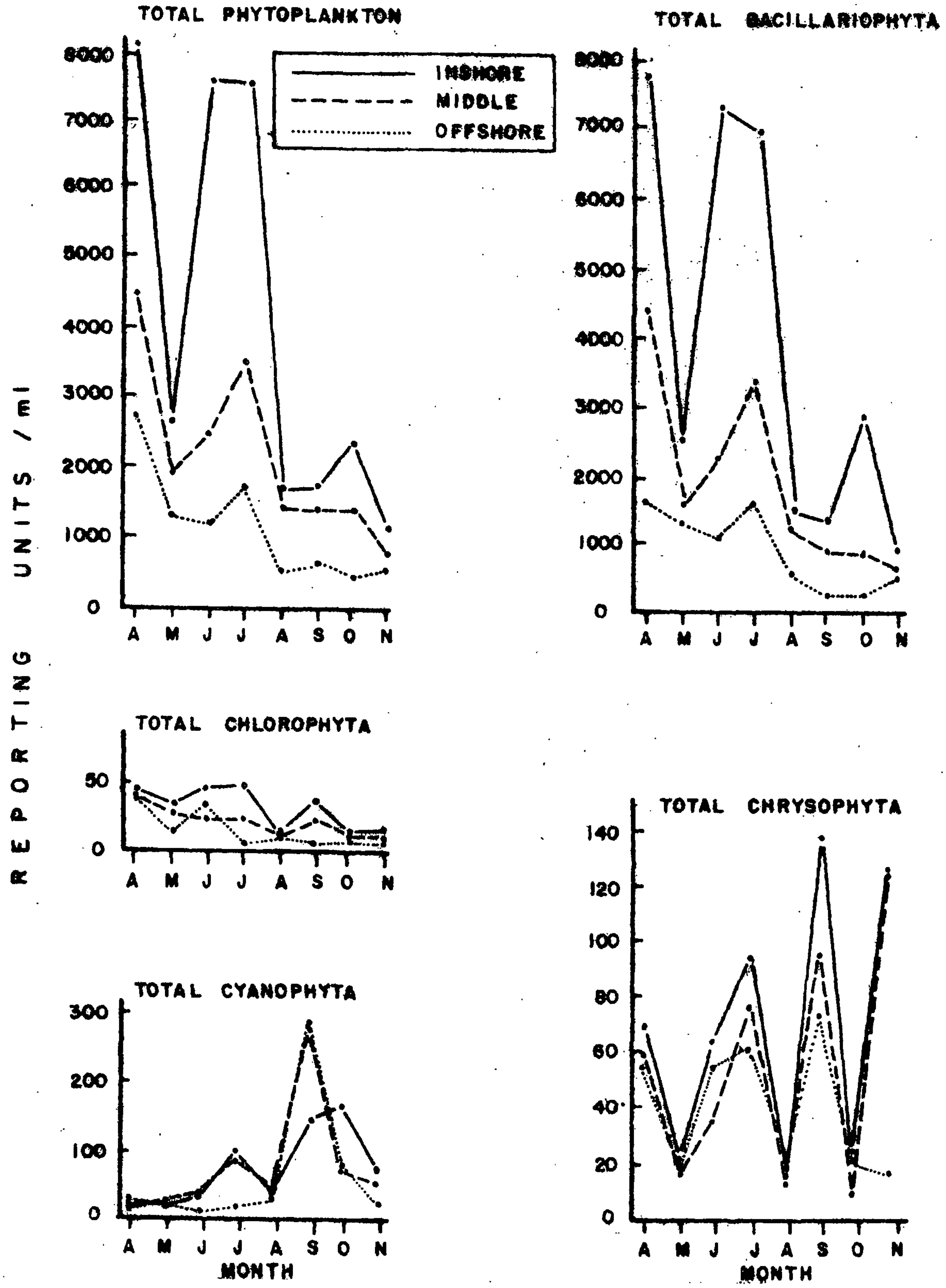


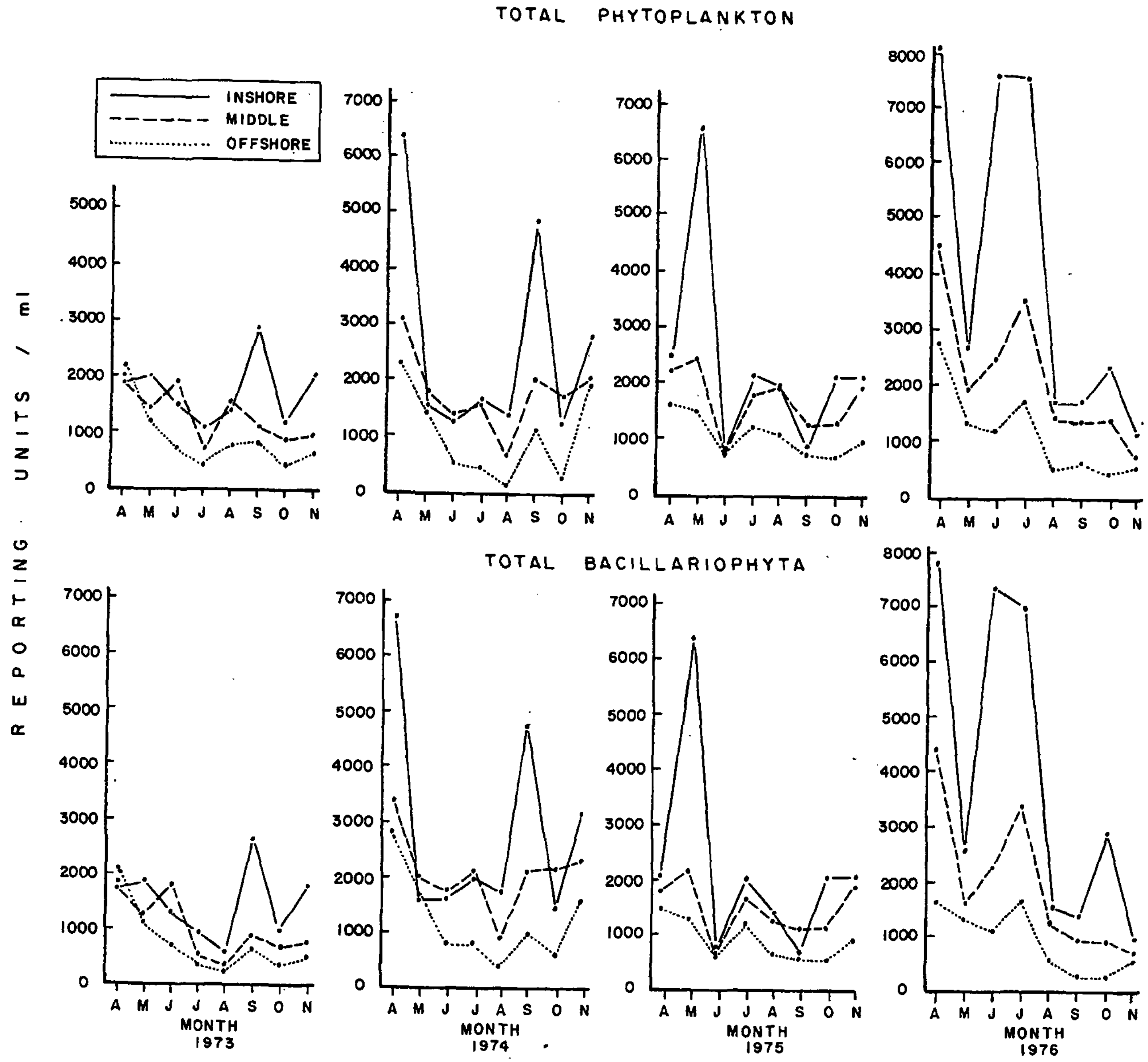
Figure 3.2. Monthly variation in abundance of total phytoplankton and four major algal divisions collected near the Kewaunee Nuclear Power Plant, April-November 1976. Each value is the mean of all locations along the depth contour.

observed during the 1973 preoperational period and the 1974-1975 operational periods with the following exceptions: (1) the population maxima at the inshore areas during 1976 were larger than in any other year and (2) the summer pulse during 1976 occurred earlier (July). The summer pulse occurred in September during 1974 and in August during 1975. These changes appear to be related to hydrologic influences and will be discussed in a later section.

Monthly phytoplankton population densities varied throughout the entire study area but generally decreased from inshore to offshore locations. The same trend was observed in previous years (Figure 3.3). In 1976, the largest numerical density (12505 reporting units/ml) occurred in July at Location 11 and the smallest numerical density (422 reporting units/ml) occurred in October at Location 14. The mean yearly density of phytoplankton was 2466 reporting units/ml.

Species diversity and evenness indices for phytoplankton ranged from 1.44 to 3.13 and from 0.37 to 0.79, respectively (Table 3.4). These values tended to be higher at the middle and offshore locations where diatom abundance was lower and also during months of relatively lower diatom production. Annual means for the two indices were 2.60 and 0.68, respectively. These values represent a slight decrease from the 1973, 1974 and 1975 mean values (Table 3.5). These slight decreases in species diversity and evenness values may be due to the increased predominance of diatoms.

Statistical analysis of total phytoplankton data revealed a number of significant differences ($P \leq 0.05$) in abundance between


TOTAL PHYTOPLANKTON

TOTAL BACILLARIOPHYTA

Figure 3.3. Monthly variation in abundance of total phytoplankton and diatoms collected in Lake Michigan near Kewaunee Nuclear Power Plant, 1973-1976.

Table 3.4. Diversity[a] (H) and evenness (J) of phytoplankton collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April - November 1976.

Sampling Location	April		May		June		July		August		September		October		November	
	H	J	H	J	H	J	H	J	H	J	H	J	H	J	H	J
Inshore																
2	2.10	0.52	3.07	0.74	1.96	0.52	2.07	0.54	2.65	0.69	2.92	0.79	2.62	0.66	2.81	0.74
11	2.71	0.69	3.02	0.76	2.03	0.50	1.44	0.37	1.99	0.50	2.75	0.70	1.85	0.47	2.90	0.74
20	2.28	0.58	2.73	0.68	2.26	0.60	2.57	0.70	2.38	0.65	2.68	0.67	2.76	0.68	3.03	0.78
Mean	2.36	0.59	2.94	0.72	2.08	0.54	2.02	0.53	2.34	0.61	2.78	0.72	2.41	0.60	2.91	0.75
Middle																
7	2.63	0.67	2.92	0.77	2.42	0.62	2.56	0.68	2.43	0.63	2.70	0.72	2.25	0.61	3.13	0.77
12	2.81	0.72	2.73	0.72	2.83	0.72	2.46	0.64	2.37	0.61	2.46	0.64	2.60	0.67	2.96	0.75
16	2.86	0.73	2.71	0.69	2.79	0.72	2.65	0.73	2.61	0.73	2.58	0.71	2.47	0.64	2.98	0.77
Mean	2.76	0.70	2.78	0.72	2.68	0.68	2.55	0.68	2.47	0.66	2.58	0.69	2.44	0.64	3.02	0.76
Offshore																
14	2.52	0.69	2.53	0.70	2.92	0.75	2.59	0.76	2.59	0.73	2.90	0.79	2.95	0.79	2.46	0.69
Mean	2.52	0.69	2.53	0.70	2.92	0.75	2.59	0.76	2.59	0.73	2.90	0.79	2.95	0.79	2.46	0.69
Monthly Mean	2.54	0.66	2.75	0.71	2.56	0.66	2.38	0.65	2.47	0.67	2.75	0.73	2.60	0.68	2.80	0.73

[a] Shannon, C. E. 1948.

Table 3.5. Mean abundance, diversity (H), and evenness (J) values for phytoplankton collected in Lake Michigan near the Kewaunee Nuclear Power Plant, 1973 - 1976.

	Monthly Means								Yearly Mean	Yearly Range Min[a]-Max[b]
	Apr	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.		
1973 Total Phytoplankton (reporting units/ml)	1975	1513	1377	706	1233	1588	828	1208	1304	332-3517
H	2.78	2.97	2.81	2.85	2.72	3.31	3.19	3.07	2.99	2.22-3.59
J	0.74	0.77	0.76	0.76	0.67	0.78	0.79	0.75	0.75	0.56-0.83
1974 Total Phytoplankton (reporting units/ml)	4434	2070	1561	1785	1187	3179	1578	2290	2290	413-9484
H	2.46	2.52	3.15	3.03	2.80	3.00	2.88	2.94	2.85	1.74-3.33
J	0.65	0.68	0.79	0.77	0.71	0.76	0.72	0.74	0.73	0.43-0.82
1975 Total Phytoplankton (reporting units/ml)	2007	3528	725	1725	1676	943	1364	1710	1710	725-3528
H	2.81	3.00	3.00	3.23	3.16	3.13	2.99	2.97	3.04	2.81-3.23
J	0.72	0.74	0.80	0.80	0.75	0.79	0.76	0.76	0.76	0.72-0.80
1976 Total Phytoplankton (reporting units/ml)	5165	1997	3754	4237	1186	1271	1266	856	2466	422-12505
H	2.54	2.75	2.56	2.38	2.47	2.75	2.60	2.80	2.60	1.44-3.13
J	0.66	0.71	0.66	0.65	0.67	0.73	0.68	0.73	0.68	0.37-0.79

[a] Minimum value at any one location.
[b] Maximum value at any one location.

locations along each of the east-west transects as well as between locations within individual depth contours (Tables 3.6 and 3.7). Occurrence of significant differences in total phytoplankton were usually reflective of distributional differences in the diatom populations. Statistically significant distributional patterns for each algal division will be described in subsequent sections.

B. Spatial and Temporal Distribution of Major Taxa

Phytoplankton were collected from areas within and outsid the influence of the thermal plume (Section II, Field and Analytica Procedures). Temperature measurements at the time of sampling revealed that Locations 11 and 12 were usually within the influence o the plume during the periods of phytoplankton sampling (Chapter 2: Water Chemistry and Bacteriology).

1. Diatoms

Diatoms (Bacillariophyta) composed 61%-97% of the monthly mean phytoplankton abundance during the entire study period and 38%-98% of the total phytoplankton abundance at any one locatio (Table 3.8). Diatom populations exhibited a bimodal seasonal cycle with spring and summer maxima in April and July, respectively. Thi observation follows the bimodal diatom periodicity patterns reporte by Damann (1966) for Lake Michigan nearshore areas. Seasonal population pulses of diatoms were also much more pronounced in the inshore locations where benthic diatoms occurred in larger numbers (Figure 3.2).

Monthly mean abundance for diatoms ranged from 672 to 5031 reporting units/ml (November and April, respectively). The

Table 3.6. Number of significant differences ($P \leq 0.05$) among inshore (10 ft), middle (20 ft) and offshore (40 ft) sampling locations for total phytoplankton and algal divisions collected near Kewaunee Nuclear Power Plant, April-November 1976. All statistical comparisons were made between locations within an individual transect or depth contour.

Compared Sampling Locations[a]	Number of Significant Differences					
	Total Phytoplankton	Bacillariophyta	Chlorophyta	Chrysophyta	Cyanophyta	Cryptophyta
Inshore > Inshore[b]	14	13	6	0	2	0
Inshore > Middle	7	7	2	0	0	0
Inshore > Offshore	7	7	3	0	0	0
Middle > Inshore	0	0	0	0	0	0
Middle > Middle[b]	7	7	0	0	2	0
Middle > Offshore	4	4	2	0	0	0
Offshore > Inshore	0	0	0	0	0	0
Offshore > Middle	0	0	0	0	0	0

[a] Inshore includes Locations 2, 11 and 20
Middle includes Locations 7, 12 and 16
Offshore includes Location 14

[b] Based on a total of 24 comparisons as opposed to eight comparisons for the other locations.

Table 3.7. Significant differences ($P \leq 0.05$) in the abundance of total phytoplankton and major phytoplankton divisions between sampling locations in Lake Michigan near the Kewaunee Nuclear Power Plant during 1976.

Phytoplankton Taxa	April I[a] M[b] O[c]	May I M O	June I M O	July I M O	August I M O	September I M O	October I M O	November I M O
Total Phytoplankton	2 v 7 11 > 12 14 16 20 (11>14) (2>20)	2 7 11 > 12 14 ^ 16 20 (11>14) (16>7)	2 ^ 7 11 > 12 14 v 16 20 (11>14) (2>20)	2 ^ 7 11 > 12 > 14 v v 16 20 (2>20) (11>14) (7>16)	2 ^ 7 11 > 12 > 14 v v 16 20 (11>14) (2>20) (7>16)	NS[d]	2 ^ 7 11 > 12 > 14 16 20 (11>14) (20>2)	2 7 11 > 12 > 14 v v 16 20 (11>14)
Total Bacillariophyta (diatoms)	2 v 7 11 > 12 14 16 20 (11>14) (2>20)	2 7 11 > 12 14 ^ 16 20 (11>14) (16>7)	2 ^ 7 11 > 12 14 v 16 20 (11>14) (2>20) (7>16)	2 ^ 7 11 > 12 > 14 v v 16 20 (11>14) (2>20) (7>16)	2 ^ 7 11 > 12 > 14 v v 16 20 (11>14) (2>20) (7>16)	2 7 11 12 > 14 16 20 (11>14)	2 ^ 7 11 > 12 > 14 v 16 20 (11>14)	2 7 11 > 12 14 16 20 (11>14)
Total Chlorophyta (green algae)	NS	NS	2 7 11 > 12 14 v 16 20 (11>14) (2>20)	2 ^ 7 11 > 12 > 14 v 16 20 (11>14)	2 ^ 7 11 12 > 14 v 16 20 (11>14)	NS	NS	NS
Total Chrysophyta (golden-brown algae)	NS	NS	NS	NS	NS	NS	NS	NS

Table 3.7. (continued)

Phytoplankton Taxa	April			May			June			July			August			September			October			November		
	I	M	O	I	M	O	I	M	O	I	M	O	I	M	O	I	M	O	I	M	O	I	M	O
Total Cyanophyta (blue-green algae)																			2					
																				7				
																				^				
		NS			NS			NS			NS			NS			NS		11	12	14		NS	
																			^	16				
																			20					
																			(20>2)	(16>7)				
Total Cryptophyta (cryptophytes)		DNA[e]			NP[f]			NS			NS			DNA			NS			NS			NS	

[a] I Inshore locations.
[b] M Middle locations
[c] O Offshore locations
[d] NS Not significant
[e] DNA Data not adequate
[f] NP Not present

NOTE: Only significant differences between locations within each depth contour and those along the same east to west transect are indicated by the > sign. All location comparisons not so indicated are considered to be equal.

Table 3.8. Mean abundance and percent composition ranges of major phytoplankton divisions at the various locations and during each month of sampling in Lake Michigan near Kewaunee Nuclear Power Plant, April-November 1976.

	Location Mean				Monthly Mean				Yearly Mean	
	Abundance (Reporting units/ml)		Percent (%)		Abundance (Reporting units/ml)		Percent (%)		Abundance (Reporting units/ml)	Percent (%)
	Min	Max	Min	Max	Min	Max	Min	Max		
Diatoms	265	11709	38.0	98.7	672	5031	61.1	97.4	2294	87.4
Blue-green algae	9	431	0.2	41.3	16	239	0.3	23.6	70	6.0
Golden-brown algae	3	207	0.3	17.0	19	102	1.1	9.2	53	3.6
Green algae	5	88	0.3	2.9	8	39	0.6	1.5	22	1.0
Cryptophytes	0	64	0.0	9.2	0	54	0.0	5.3	18	2.0

largest single assemblage of diatoms (11709 reporting units/ml) occurred in July at Location 11 and the smallest assemblage (265 reporting units/ml) occurred in September at Location 14. Although these values were within the diatom density ranges observed in the KNPP area during the 1973 preoperational period (Everhart and Rasgus 1974) and the 1974-1975 operational periods (Festin 1975, 1976), the yearly mean diatom density in 1976 was greater than in any previous year (Table 3.9). Especially during April and June, diatom densities at the inshore locations were larger than during corresponding periods in previous years. These higher diatom densities were largely due to an increased abundance of benthic pennate forms. Many of these benthic forms (such as _Fragilaria_ _pinnata_) are "opportunistic" taxa in that they will cohabit as members of the phytoplankton assemblage as well as the benthic assemblage.

There were 156 diatom taxa represented among 27 genera identified throughout the study; however, only 19 taxa were dominant at at least one or more location during at least one sampling period. As previously stated, six diatom species were dominant in at least four of the eight months of sampling. They were, in order of decreasing dominance _Fragilaria_ _pinnata_, _F_. _crotonensis_, _F_. _vaucheriae_, _Tabellaria_ _flocculosa_, _Asterionella_ _formosa_ and _Cyclotella_ _kutzingiana_ var. _radiosa_.

The spatial and temporal variability of the six dominant diatoms in the KNPP area was primarily a result of seasonal and depth contour differences. _Fragilaria_ _crotonensis_ and _A._ _formosa_ are euryplanktonic (truly floating) while _F_. _pinnata_,

Table 3.9. Yearly mean[a] density and percent composition of total phytoplankton and major algal divisions in Lake Michigan near the Kewaunee Nuclear Power Plant, 1973-1976.

	1973		1974		1975		1976	
	Reporting units/ml	%	Reporting units/ml	%	Reporting units/ml	%	Reporting units/ml	%
Bacillariophyta (diatoms)	1070	82	2114	90	1521	88	2294	87
Cyanophyta (blue-green algae)	141	11	94	5	61	5	70	6
Chrysophyta (golden-brown algae)	39	3	55	3	76	4	53	4
Chlorophyta (green algae)	30	2	20	1	25	2	22	1
Other algae	4	2	7	1	27	1	27	2
Total Phytoplankton	1304		2290		1710		2466	

[a] Density and percentage means are based on a total of eight months of samples (April-November).

F. vaucheriae and T. flocculosa are generally considered periphytic (Lowe 1974). However, as previously mentioned, these periphytic forms are commonly encountered "opportunists". Fragilaria crotonensis and F. pinnata were the most abundant species (being dominant every month)(Table 3.2); although F. crotonensis generally occurred in relatively large numbers at all locations while F. pinnata tended to be more abundant at the inshore locations. Tabellaria flocculosa was dominant in spring and early summer with higher densities towards the inshore area and A. formosa was dominant in spring and fall with generally uniform density throughout the study area. Fragilaria vaucheriae was only occasionally dominant, occurring in larger numbers at certain inshore and middle locations during the seasonal diatom peak periods. Cyclotella kutzingiana var. radiosa, a centric not previously reported in the area and probably a euryplanktonic species, was dominant at some inshore and middle locations during the summer and fall sampling periods. No ecological indicator status of this taxon has ever been reported. The occurrence of the euryplanktonic diatoms appeared to be more seasonally related; whereas the number and distribution of periphytic forms in the plankton was probably more largely determined by hydrologic factors.

Significant ($P \leq 0.05$) differences in diatom abundance occurred between locations along each east-west transect and also between locations within a depth contour (Table 3.6). During all months, except September, diatom populations at the inshore Location 11 were significantly more abundant than at the middle and offshore locations (Locations 12 and 14, respectively)(Table 3.7). However, these greater diatom densities were not exclusively confined to Location 11. During April the largest diatom density was found at the north inshore control location (Location 2)(Table 3.1). Diatom densities at the middle (20 ft depth contour) locations were only occasionally significantly different.

The following differences between 1976 diatom densities and those recorded in previous years occurred:

a. Total diatom density during 1976 showed an increase over previous years at the inshore locations where a greater abundance of benthic forms occurred in the plankton.

b. The relatively larger 1976 summer diatom pulse occurred in June and July; whereas the 1973 and 1974 summer pulses occurred in September. The near absence of an identified 1975 summer diatom pulse was probably due to unusual weather conditions (Festin 1976).

c. The number of significant ($P \leq 0.05$) differences in 1976 diatom densities among inshore and middle locations increased over that of previous years (Table 3.10).

All these changes appear to be related to hydrologic influences which will be discussed in a subsequent section.

2. Blue-green Algae

Blue-green algae (Cyanophyta) were represented by 19 species (Appendix 3-A) and composed the second most abundant algal division (Table 3.9). They were very sparse from April to August but produced a small pulse in September (Figure 3.2). Blue-green populations in September ranged from 140 to 431 reporting

Table 3.10. Yearly number of significant differences ($P < 0.05$) among inshore (10 ft), middle (20 ft) and offshore (40 ft) sampling locations for diatoms collected monthly (April-November) during 1973 to 1976. All statistical comparisons were made between locations within an individual transect or depth contour.

Compared Sampling Locations[a]	Number of Significant Differences			
	1973	1974	1975	1976
Inshore > Inshore	13	10	10	13
Inshore > Middle[b]	4	3	3	7
Inshore > Offshore	15	18	15	7[b]
Middle > Inshore[b]	0	1	0	0
Middle > Middle	4	5	7	7
Middle > Offshore[b]	6	6	4	4
Offshore > Inshore	0	0	0	0[b]
Offshore > Middle[b]	0	0	0	0
Offshore > Offshore	3	7	2	DNC[c]

[a] Inshore includes Locations 2, 11 and 20
Middle includes Locations 7, 12 and 16
Offshore includes Locations 14, 23 and 24

[b] Based on a total of eight comparisons as opposed to 24 comparisons for the other locations.

[c] Data not comparable.

units/ml (Table 3.1) and composed 7% to 41% of the total phytoplankton density. This relatively small summer pulse was similar to that recorded during 1975 and considerably smaller than the August or September peaks recorded in 1973 and 1974 (Figure 3.4).

Coeloephaerium naegelianum appeared to have gained predominance in the blue-green algal assemblage as populations of other species diminished. Statistically significant (P_0.05) differences among locations were not observed during the peak blue-green crop in September (Table 3.7).

3. Golden-Brown Algae

The golden-brown algae (Chrysophytes) were represented by 14 genera and 19 species. They generally occurred in small numbers and became prominent only when the total phytoplankton population was relatively small. Golden-brown algae densities never exceeded 207 reporting units/ml or 17% of the total phytoplankton. Yearly mean abundance and percent composition of golden-brown algae were 53 reporting units/ml and 3.6%, respectively (Table 3.1). These values fall within the ranges of yearly mean abundance and percent composition recorded in previous years (Table 3.8 and 3.9). There was a similar seasonal variation at all locations of alternate periods of high and low densities (Figure 3.2). *Dinobryon divergens* and *D. sociale* were the most abundant golden-brown algal species. Statistically significant ($P \leq 0.05$) differences in golden-brown algae populations were not observed among the various locations throughout the entire year of study.

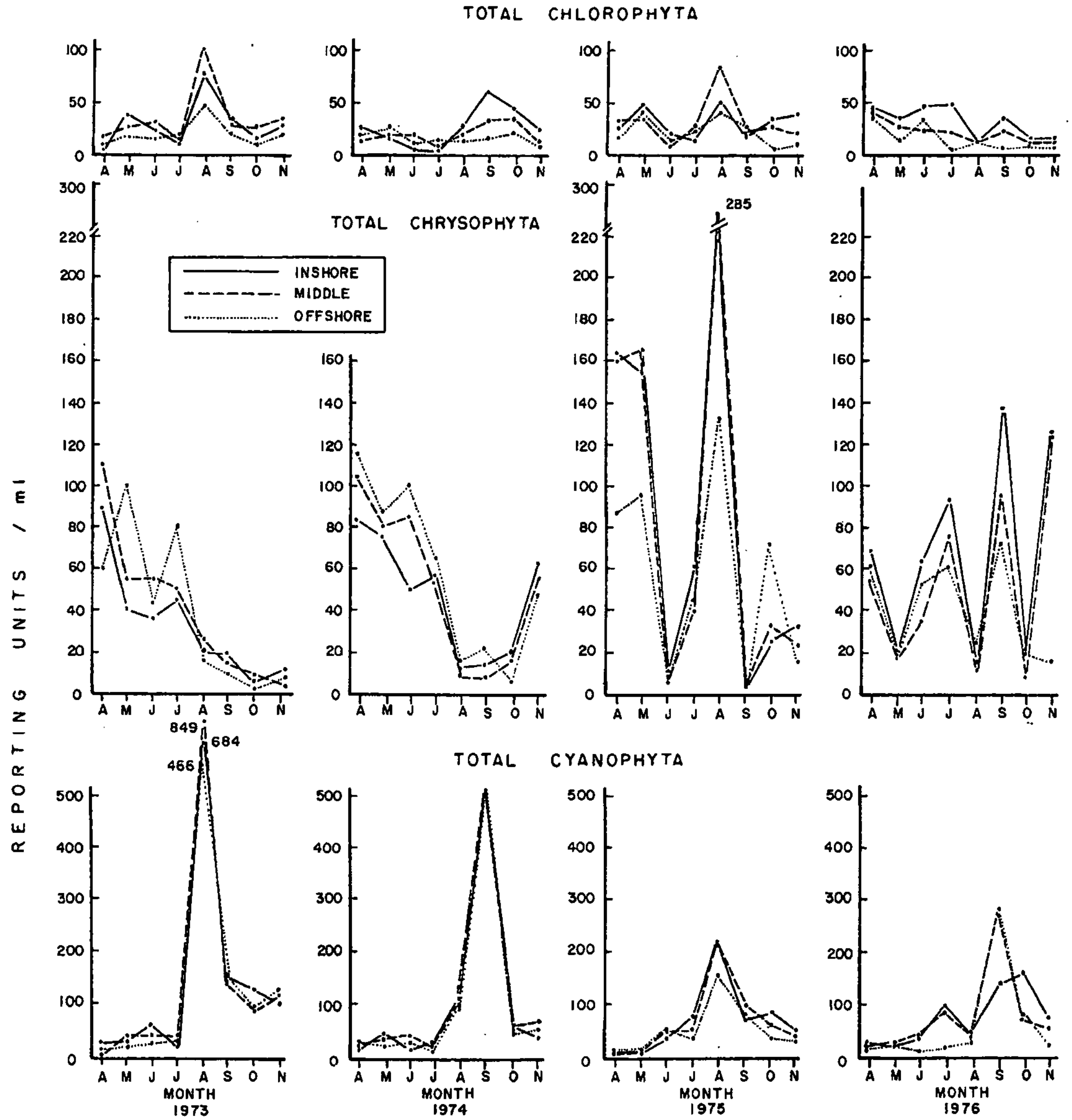


Figure 3.4. Monthly variation in abundance of green, golden-brown and blue-green algae collected in Lake Michigan near Kewaunee Nuclear Power Plant, 1973-1976.

4. Green Algae

Green algae (Chlorophyta) were represented by 31 genera and 57 species. As in previous years this group comprised the second most diverse algal division, although their densities remained low throughout the entire study. Green algal densities ranged from 5 to 88 reporting units/ml with a yearly mean of 22 reporting units/ml (Table 3.8). They never exceeded 3% of the total phytoplankton at any location. These values were within the range recorded for the KNPP study site in previous years (Table 3.9) Some statistically significant ($P \leq 0.05$) differences in green algae populations were observed between locations along Transect III and between locations along the 10 ft depth contour (Table 3.7).

5. Cryptophytes

The cryptophytes (Cryptophyta) were represented by two species. They never exceeded 64 reporting units/ml or comprised more than 9% of the total phytoplankton (Table 3.1). As in the previous years, the cryptophytes became slightly more prominent during the fall months. There were no statistically significant ($P \leq 0.05$) differences among locations in cryptophyte densities.

C. Relationship between Phytoplankton and Physicochemical Parameters

Day to day variations and seasonal fluctuations in phytoplankton populations are inevitable because of the influence of numerous environmental factors. The most important environmental variables that determine the composition and size of phytoplankton populations are day-length, temperature, currents, and nutrients. In the subsequent discussion some of the physicochemical factors that may have caused changes in the phytoplankton community near KNPP will be assessed.

1. Diatoms

Seasonal fluctuation in diatom populations were basically determined by water temperature and the availability of nutrients, particularly silica. The relatively large April diatom pulse was most likely a part of a spring pulse that was already in a downward trend following the depletion of soluble silica (Figure 3.5). In May, the population continued to decline as silica was still below the limiting concentration of 0.5 mg Si/l required for diatom growth (Lund 1965). In June, the diatom population increased sharply, probably due to an upwelling that brought benthic diatoms into the plankton. The occurrence of the upwelling was apparent from the low temperatures of near-surface water throughout the study area and also from the sudden increase of soluble silica concentrations in the surface water (Chapter 2: Water Chemistry and Bacteriology). As turbulence (resulting from the upwelling) decreased in July, benthic diatoms in the plankton probably began to sink. At the same time, soluble silica decreased to below the limiting concentration and the water temperature increased beyond the optimum range of the diatoms, resulting in a sharp drop in diatom densities in August.

Although water temperature has an influence on the metabolism and growth of all algae, a direct relationship between temperature and spatial distribution of diatom populations was not apparent (Figure 3.6). At locations along the 10 and 20 foot depth

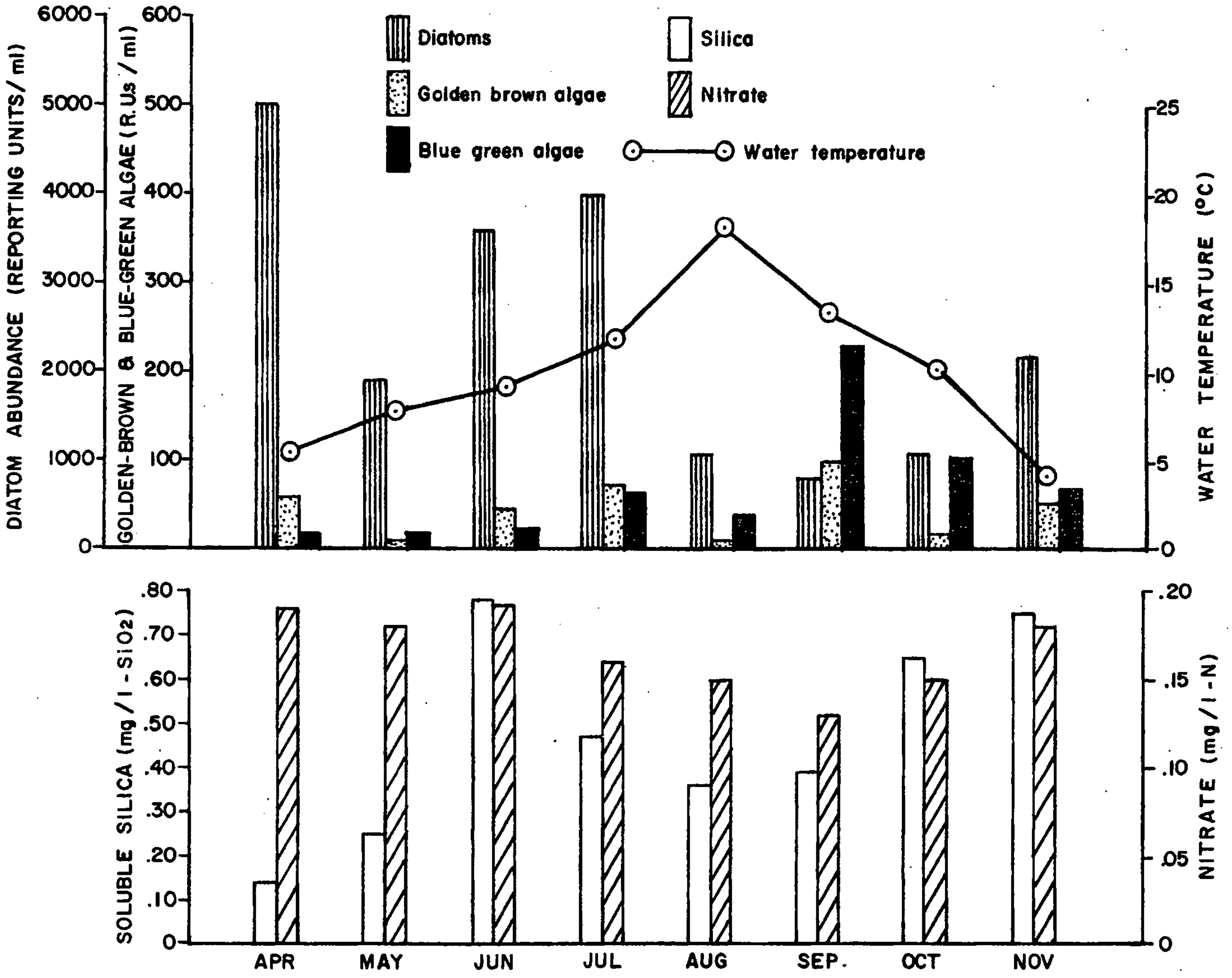


Figure 3.5. Monthly mean density of diatoms, golden-brown and blue-green algae compared with water temperature and concentrations of silica and nitrate in samples collected from Lake Michigan near Kewaunee Nuclear Power Plant, April-November 1976.

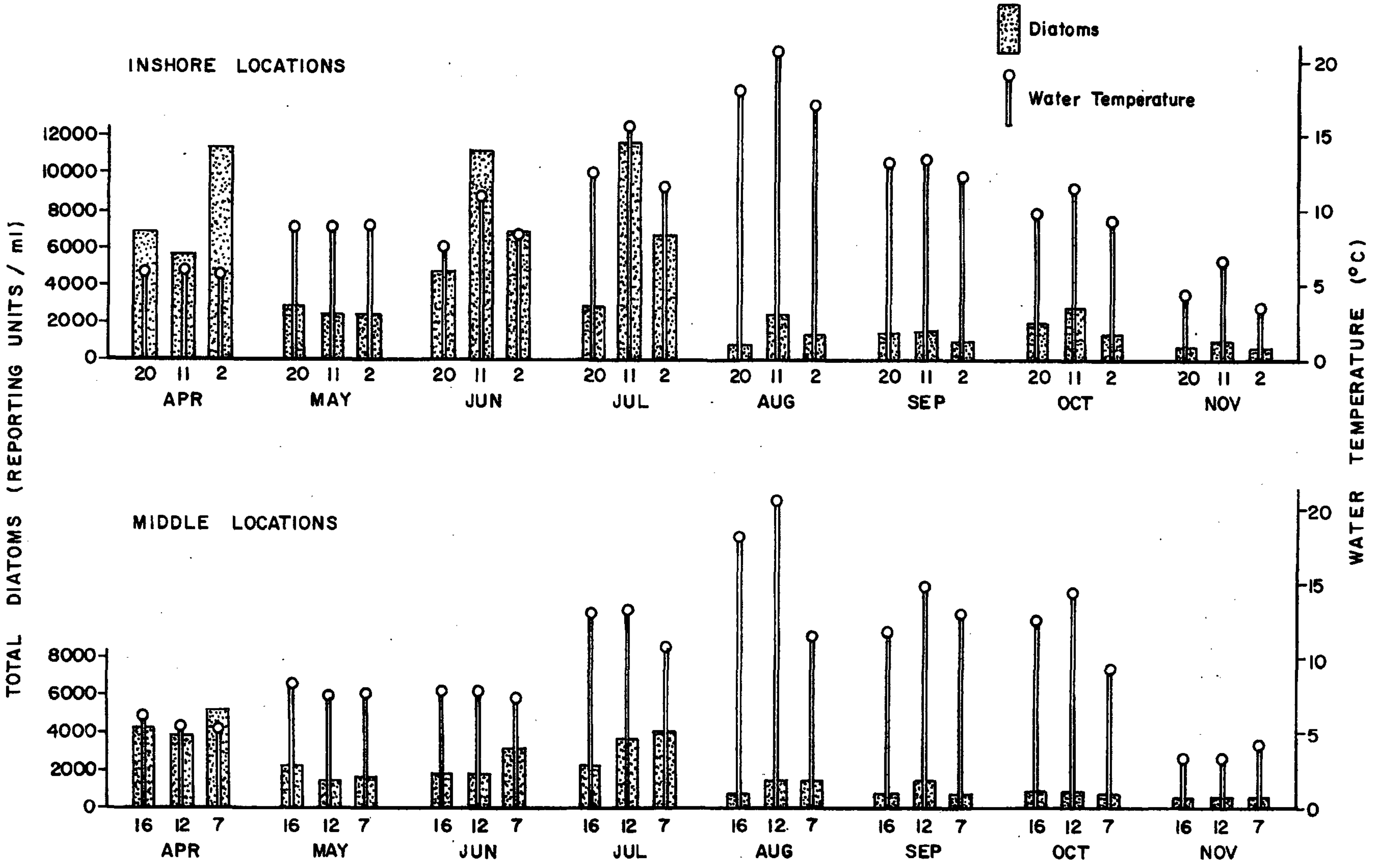


Figure 3.6. Total diatom density and water temperature at inshore and middle locations in Lake Michigan near the Kewaunee Nuclear Power Plant, April-November 1976.

contours larger diatom densities were not consistently associated with warmer water.

Increased abundance of benthic diatoms in the inshor area plankton appeared to be due to increased scouring of the botto resulting from the combined effects of the discharged cooling water and the natural nearshore currents of the lake. Similar observations were made during the 1974 and 1975 operational periods.

2. Other Algae

Seasonal fluctuation in populations of algae other than diatoms appeared to be less directly correlated with nutrients and temperature. Golden-brown algal densities were low in spring although temperature and nitrate concentrations were within the same range of values that were associated with higher populations in previous years. In summer and fall their densities alternately increased and decreased independently of the temperature and nutrients. Blue-green algal densities peaked in September when water temperature was approximately 14 C but did not show a comparable peak in July when water temperature was the same. The increase in blue-greens in September was associated with a decrease in nitrate concentration (Figure 3.5). Population densities during this period did not show statistically significant ($P \leq 0.05$) differences between locations and did not appear to be related with the thermal plume.

IV. Summary and Conclusions

1. Phytoplankton collected near Kewaunee Nuclear Power Plant included seven major algal divisions. The five most abundant divisions in decreasing order were Bacillariophyta (diatoms), Cyanophyta (blue-green algae), Chrysophyta (golden-brown algae), Chlorophyta (green algae) and Cryptophyta. This same order of abundance was observed during the 1972-1973 preoperational periods and 1974-1975 operational periods of phytoplankton monitoring near KNPP.

2. There were some new taxa not reported in the previous monitoring programs which replaced some previously reported taxa. This replacement was confined to the rarer forms which were reported intermittently at all locations. The total number of taxa and the most abundant forms were similar to those reported in previous years.

3. Phytoplankton densities were generally larger in 1976 than densities of any other previous year. This increase reflected diatom densities and was not exclusively related to Plant operation since it occurred at both the discharge location and control locations in the inshore area.

4. The dominant species changed very little from 1971 to 1976. Diatoms were always the most abundant group and comprised the largest number of species. *Fragilaria crotonensis*, *F. pinnata*, and *Tabellaria flocculosa* continued to be the most abundant species throughout the entire study area.

5. Blue-green algae, primarily represented by *Coelosphaerium naegelianum*, were most abundant at all locations in September.

Summer peak densities in 1976 were similar to the 1975 densities but lower than those in 1973 and 1974.

6. Golden-brown algal densities were lower than in 1975. There was a seasonal increase and decrease in their densities through the summer and fall. Dinobryon divergens and D. sociale were the most common species.

7. Green algae were represented by a relatively large number of taxa even though they were present in small number and never comprised more than 3% of the total phytoplankton.

8. Phytoplankton densities were usually significantly ($P \leq 0.05$) more abundant at the inshore locations than at the middle and offshore locations. This was also true for the division Bacillariophyta (diatoms) which exhibited the same distributional patterns during the previous studies near KNPP and was interpreted to be due to normal shoreline effect.

9. Differences in diatom densities at locations within and outside the influence of the thermal plume did not appear to be related to differences in water temperature.

The scouring of periphytic diatoms by discharge canal currents and their subsequent incorporation into the plankton was probably the primary cause of the usually higher diatom densities reported in the immediate discharge area. This pattern was also observed during the 1974 and 1975 operational periods.

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NALCO ENVIRONMENTAL SCIENCES

Chapter 4

ZOOPLANKTON

Janet M. Urry and P. S. Bartholomew

OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR
KEWAUNEE NUCLEAR POWER PLANT

SIXTH ANNUAL REPORT
January-December 1976

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Chapter 4

ZOOPLANKTON

Janet M. Urry and P. S. Bartholomew

I. Introduction

The zooplankton community in Lake Michigan near the Kewaunee Nuclear Power Plant (KNPP) was studied in 1976 as part of the third year of operational monitoring for the Plant. The monitoring program included: (a) identification of the populations which composed the community; and (b) analysis of the populations to determine natural, seasonal fluctuations and variations among areas.

The specific objectives of the 1976 study were to compare zooplankton populations in the immediate area of the Plant to populations in control locations. These comparisons were made to determine whether thermal effluents from the KNPP were affecting the zooplankton community in the area.

II. Field and Analytical Procedures

Sixty zooplankton samples were collected on eight monthly sampling dates in 1976: 27 April, 18 May, 15 June, 20 July, 24 August, 22 September, 19 October and 16 November. Four replicate samples were obtained from each of 15 locations (Figure 1 and Table 1, General Introduction and Summary). Each sample was a composite of two simultaneous vertical tows using 30 cm diameter, conical Nytex plankton nets of No. 25 mesh (64 μ aperture). Tows were made from a depth of 3 m to the surface at the 10 ft (3.05 m) depth contour (Locations 2, 6, 11, 15 and 20), from a depth of 6 m to the surface at the 20 ft (6.1 m) depth contour (Locations 3, 7, 12, 16 and 21) and from a depth of 9 m to the surface at the 30 ft (9.14 m) depth contour (Locations 4, 8, 13, 17 and 22).

Each sample was prepared as follows:

(a) A non-clouding surfactant was added to reduce clumping

(b) Carbonated water was added as a relaxant to aid in rotifer identification;

(c) Five percent formalin was added as a preservative.

In the laboratory, subsamples were placed in a Bogorov counting chamber or Petri dish and the organisms were identified and counted using a stereozoom dissecting microscope. Any organism which could not be identified was removed from the chamber, mounted on a slide and examined at higher magnification using a compound microscope.

A stratified counting procedure was employed for sample analysis. One replicate from each of the locations was randomly subsampled and a count was made of the zooplankton. The sample from each depth contour with the lowest density of organisms was concentrated or diluted so that a working density of approximately 300 organisms was obtained in a random subsample. Three or four subsamples were then analyzed with all taxa identified and enumerated. In a next larger subsample, the only taxa enumerated were those which had been observed at a density of less than 50 organisms in the first four subsamples. A further subsample was occasionally analyzed for rare taxa (taxa observed at a density of less than 50 organisms in the previous subsamples) so that at least 10% of the total sample volume was examined. All samples from each respective depth contour were uniformly concentrated and analyzed using the same subsample volumes.

All Crustacea were identified to species and gender with the exception of immature copepods which were identified as nauplii, calanoid copepodites or cyclopoid copepodites. All Rotifera were identified to genus. Identifications were made using taxonomic keys and descriptions by Brooks (1957), Edmondson (1959), Frey (1959, 1961), Megard (1967), Fryer (1968), Carpenter et al. (1973), Smirnov (1971) and Ruttner-Kolisko (1972).

Population densities were reported as numbers of organisms per cubic meter (No./m^3). To obtain monthly mean densities, the contour means were weighted according to the following scheme:

$$\frac{A + 2B + 3C}{6} = \text{monthly mean density}$$

where A = the mean density of the 10 ft depth contour locations;

B = the mean density of the 20 ft depth contour locations;

and C = the mean density of the 30 ft depth contour locations.

Zooplankton taxa which were present in sufficient densities each month were statistically compared among locations on a depth contour. A non-parametric Kruskal-Wallis analysis of variance was applied to the data (Siegel 1956). Following the Kruskal-Wallis analysis an appropriate multiple comparison procedure (Miller 1966) was performed in an attempt to locate specific differences between the locations. Statistical analyses were performed at $P \leq 0.05$. Diversity indices were calculated to the log base 2 for each location in each month according to the formula of Shannon (1948).

III. Results and Discussion

A. Taxa Observed in the Zooplankton Community

Eighty two adult and juvenile zooplankton taxa were identified in the study area near KNPP in 1976 (Table 4.1). The taxa encountered were relatively unchanged from those observed in previous years. Of particular note was the observation of substantial populations of Chydorus gibbus, Ascomorpha, and Chromogaster, which, though not new to our study, were extremely rare or absent in former years (Industrial BIO-TEST Laboratories, Inc. 1973, Urry 1974, 1975, 1976). During the 1976 period there were five taxa that were observed for the first time in the study area. The new taxa were Macrocyclops albidus, a copepod; Chydorus ovalis and Ilyocryptus acutifrons, cladocerans; and Colurella and Pleurotrocha, rotifers. None of these taxa composed as much as 0.1% of the zooplankton assemblage on any sampling date and only one specimen each of M. albidus and C. ovalis was sighted.

One copepod and three cladocera which were solitary or rare in 1975 were not sighted in 1976. The copepod was Learnea sp. and the cladocera were Alona setulosa, Pleuroxus denticulatus, and Ilyocryptus sordidus. The absence of these taxa is probably of no consequence to the ecology of the zooplankton community since they were of solitary or occasional occurrence.

B. Seasonal Variations in the Zooplankton Community

Monthly mean densities were calculated for all taxa observed (Table 4.1). Total density in the zooplankton community was somewhat stable during April, May and June, i.e., 95,000,

Table 4.1. Monthly and yearly mean densities and percent composition of zooplankton organisms collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

	27 April		18 May		15 June		20 July		24 August	
	No./m^3	%	No./m^3	%	No./m^3	%	No./m^3	%	No./m^3	%
Crustacea										
Copepoda										
nauplii	7,253	7.7	7,194	8.4	4,982	7.0	55,903	8.0	13,689	10.6
calanoid copepodites	49	0.1	137	0.2	549	0.8	5,649	0.8	1,467	1.1
cyclopoid copepodites	63	0.1	130	0,2	2,326	0.6	7,791	1.1	3,089	2.5
Cyclops bicuspidatus thomasi	335	0.4	216	0.3	93	0.1	2,372	0.3	794	0.6
Cyclops vernalis	*[a]	Tr[b]	0	0.0	*	Tr	9	Tr	1	Tr
Diaptomus ashlandi	345	0.3	161	0.2	57	Tr	389	Tr	181	0.1
Diaptomus minutus	161	0,2	88	0.1	14	Tr	2	Tr	6	Tr
Diaptomus oregonensis	391	0.4	69	0.1	3	Tr	44	Tr	32	Tr
Diaptomus sicilis	38	Tr	2	Tr	0	0.0	5	Tr	*	Tr
Diaptomus siciloides	0	0.0	0	0.0	0	0.0	1	Tr	0	0.0
Epischura lacustris	0	0.0	0	0.0	0	0.0	0	0.0	4	Tr
Ergasilus spp.	0	0.0	0	0.0	0	0.0	*	Tr	0	0.0
Eucyclops agilis	*	Tr	*	Tr	1	Tr	3	Tr	0	0.0
Eucyclops prionophorus	0	0.0	0	0.0	0	0.0	*	Tr	*	Tr
Eurytemora affinis	0	0.0	0	0.0	0	0.0	4	Tr	1	Tr
Limnocalanus macrurus	17	Tr	*	Tr	0	0.0	0	0.0	*	Tr
Macrocyclops albidus	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Mesocyclops edax	0	0.0	0	0.0	0	0.0	1	Tr	17	Tr
Paracyclops fimbriatus poppei	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Tropocyclops prasinus mexicanus	5	Tr	9	Tr	5	Tr	292	Tr	165	0.1
Total Copepoda	8,657	9.1	8,006	9.3	8,030	11.2	72,465	10.4	19,446	15.0
Cladocera										
Acroperus harpae	0	0.0	0	0.0	0	0.0	0	0.0	1	Tr
Alona barbulata	*	Tr	0	0.0	0	0.0	*	Tr	*	Tr
Alona circumfimbriata	1	Tr	0	0.0	*	Tr	5	Tr	2	Tr
Alona guttata	0	0.0	0	0.0	0	0.0	*	Tr	*	Tr
Alona pulchella	0	0.0	0	0.0	0	0.0	*	Tr	0	0.0
Alona quadrangularis	2	Tr	0	0.0	0	0.0	*	Tr	5	Tr
Alona sp.	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Biapertura affinis	1	Tr	0	0.0	0	0.0	1	Tr	3	Tr
Bosmina longirostris	104	0.1	366	0.4	178	0.2	20,599	2.9	12,272	9.5
Camptocercus lilljeborgi	0	0,0	0	0.0	0	0.0	*	Tr	0	0.0
Ceriodaphnia lacustris	0	0.0	0	0.0	0	0.0	*	Tr	*	Tr
Ceriodaphnia quadrangula	0	0.0	0	0.0	0	0.0	*	Tr	*	Tr
Chydorus gibbus	0	0.0	0	0.0	0	0.0	174	Tr	32	Tr
Chydorus ovalis	0	0.0	0	0.0	*	Tr	0	0.0	0	0.0
Chydorus sphaericus	4	Tr	1	Tr	49	Tr	116	Tr	132	0.1
Daphnia galeata mendotae	3	Tr	2	Tr	0	0.0	*	Tr	195	0.2
Daphnia longiremis	10	Tr	2	Tr	40	Tr	112	Tr	27	Tr
Daphnia parvula	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Daphnia retrocurva	3	Tr	1	Tr	0	0.0	187	Tr	1,588	1.2
Daphnia schodleri	0	0.0	0	0.0	0	0.0	*	Tr	0	0.0
Diaphanosoma brachyurum	0	0.0	0	0.0	0	0.0	*	Tr	0	0.0
Diaphanosoma leuchtenbergianum	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0

Table 4.1. (continued)

	27 April		18 May		15 June		20 July		24 August	
	No./m^3	%	No./m^3	%	No./m^3	%	No./m^3	%	No./m^3	%
Disparalona rostrata	*	Tr	0	0.0	*	Tr	*	Tr	*	Tr
Eubosmina coregoni	4	Tr	*	Tr	1	Tr	963	0.1	71	Tr
Eurycercus lamellatus	0	0.0	0	0.0	0	0.0	1	Tr	2	Tr
Holopedium gibberum	0	0.0	0	0.0	0	0.0	*	Tr	*	Tr
Ilyocryptus acutifrons	0	0.0	0	0.0	0	0.0	*	Tr	0	0.0
Ilyocryptus spinifer	0	0.0	*	Tr	0	0.0	0	0.0	*	Tr
Leptodora kindtii	0	0.0	0	0.0	0	0.0	*	Tr	1	Tr
Leydigia leydigi	1	Tr	*	Tr	*	Tr	1	Tr	*	Tr
Macrothrix laticornis	*	Tr	*	Tr	0	0.0	1	Tr	0	0.0
Polyphemus pediculus	0	0.0	0	0.0	0	0.0	0	0.0	3	Tr
Total Cladocera	135	0.1	374	0.4	270	0.4	22,162	3.2	14,336	11.1
Rotifera										
Anuraeopsis	1	Tr	2	Tr	49	0.1	62	Tr	20	Tr
Ascomorpha	0	0.0	0	0.0	9	Tr	285	Tr	939	0.7
Asplanchna	3	Tr	3	Tr	38	Tr	0	0.0	36	Tr
Bdelloid rotifers	9	Tr	4	Tr	16	Tr	52	Tr	15	Tr
Brachionus	23	0.6	76	0.1	17	Tr	15	Tr	2	Tr
Cephalodella	10	Tr	8	Tr	186	0.3	7	Tr	0	0.0
Chromogaster	0	0.0	0	0.0	0	0.0	24	Tr	505	0.4
Collotheca	9	Tr	2	Tr	*	Tr	523	0.1	1,610	1.2
Colurella	1	Tr	0	0.0	23	Tr	0	0.0	8	Tr
Conochilus	9	Tr	15	Tr	14	Tr	84	Tr	144	0.1
Dicranophorus	0	0.0	0	0.0	11	Tr	7	Tr	1	Tr
Encentrum	13	Tr	7	Tr	1	Tr	0	0.0	0	0.0
Euchlanis	6	Tr	9	Tr	21	Tr	60	Tr	5	Tr
Filinia	27	Tr	67	0.1	488	0.7	459	0.1	97	0.1
Gastropus	0	Tr	1	0.0	2	Tr	6,651	1.0	81	0.1
Kellicottia	571	0.6	1,218	1.4	3,449	4.8	32,013	4.6	1,511	1.2
Keratella	1,465	1.5	2,953	3.4	7,462	10.4	119,941	17.2	21,950	17.0
Lecane	0	0.0	0	0.0	0	0.0	8	Tr	0	0.0
Lepadella	0	0.0	1	Tr	3	Tr	7	Tr	0	0.0
Monostyla	1	Tr	0	0.0	1	Tr	67	Tr	569	0.4
Notholca	29,343	30.9	10,726	12.5	7,381	10.3	909	0.1	131	0.1
Notommata	0	0.0	1	Tr	1	Tr	0	0.0	0	0.0
Pleurotrocha	0	0.0	0	0.0	1	Tr	0	0.0	0	0.0
Ploesoma	15	Tr	90	0.1	7,004	9.8	7,766	1.1	874	0.7
Polyarthra	1,080	1.1	4,925	5.7	14,385	20.1	390,562	55.9	49,163	38.0
Pompholyx	0	0.0	0	0.0	0	0.0	115	Tr	16	Tr
Proales	0	0.0	0	0.0	1	Tr	0	0.0	1	Tr
Synchaeta	53,413	56.3	57,357	74.6	22,369	31.2	30,481	4.4	13,820	10.7
Trichocerca	16	Tr	22	Tr	411	0.6	13,856	2.0	4,053	3.1
Trichotria	1	Tr	0	0.0	2	Tr	89	Tr	1	Tr
Total Rotifera	86,016	90.7	77,487	90.2	63,345	88.3	604,043	86.5	95,552	73.9
Total Zooplankton	94,808		85,867		71,645		698,669		129,334	

[a] * Taxon present in densities less than $1/m^3$.

[b] Tr - Trace

Table 4.1. (continued)

	22 September		19 October		16 November		1976 Yearly Mean	
	No./m^3	%	No./m^3	%	No./m^3	%	No./m^3	%
Crustacea								
Copepoda								
nauplii	20,063	7.3	6,409	7.9	2,299	5.2	14,724	8.0
calanoid copepodites	4,451	1.6	4,154	5.1	2,820	6.4	2,410	1.3
cyclopoid copepodites	12,963	4.7	9,650	11.9	4,053	9.2	5,008	2.7
Cyclops bicuspidatus thomasi	1,211	0.4	474	0.6	460	1.0	744	0.4
Cyclops vernalis	6	Tr	10	Tr	0	0.0	3	Tr
Diaptomus ashlandi	255	0.1	101	0.1	149	0.3	205	0.1
Diaptomus minutus	37	Tr	26	Tr	63	0.1	50	Tr
Diaptomus oregonensis	67	Tr	79	0.1	640	1.5	166	0.1
Diaptomus sicilis	3	Tr	92	0.1	31	0.1	21	Tr
Diaptomus siciloides	*	Tr	0	0.0	0	0.0	*	Tr
Epischura lacustris	47	Tr	57	0.1	321	0.7	54	Tr
Ergasilus spp.	0	0.0	0	0.0	0	0.0	*	Tr
Eucyclops agilis	1	Tr	0	0.0	*	Tr	1	Tr
Eucyclops prionophorus	0	0.0	0	0.0	0	0.0	*	Tr
Eurytemora affinis	9	Tr	*	Tr	4	Tr	2	Tr
Limnocalanus macrurus	0	0.0	3	Tr	5	Tr	3	Tr
Macrocyclops albidus	*	Tr	0	0.0	0	0.0	*	Tr
Mesocyclops edax	105	Tr	37	Tr	1	Tr	20	Tr
Paracyclops fimbriatus poppei	*	Tr	0	0.0	0	0.0	*	Tr
Tropocyclops prasinus mexicanus	1,010	0.4	291	0.4	129	0.3	238	0.1
Total Copepoda	40,228	14.7	21,383	26.3	10,975	24.9	23,649	12.8
Cladocera								
Acroperus harpae	*	Tr	0	0.0	0	0.0	*	Tr
Alona barbulata	*	Tr	0	0.0	*	Tr	*	Tr
Alona circumfimbriata	*	Tr	1	Tr	*	Tr	1	Tr
Alona guttata	0	0.0	0	0.0	0	0.0	*	Tr
Alona pulchella	0	0.0	0	0.0	0	0.0	*	Tr
Alona quadrangularis	1	Tr	*	Tr	0	0.0	1	Tr
Alona sp.	*	Tr	0	0.0	0	0.0	*	Tr
Biapertura affinis	1	Tr	0	0.0	0	0.0	1	Tr
Bosmina longirostris	47,681	17.5	8,248	10.1	1,076	2.4	11,316	6.1
Camptocercus lilljeborgi	0	0.0	0	0.0	0	0.0	*	Tr
Ceriodaphnia lacustris	14	Tr	*	Tr	0	0.0	2	Tr
Ceriodaphnia quadrangula	79	Tr	1	Tr	*	Tr	10	Tr
Chydorus gibbus	18	Tr	6	Tr	1	Tr	29	Tr
Chydorus ovalis	0	0.0	0	0.0	0	0.0	*	Tr
Chydorus sphaericus	203	0.1	30	Tr	*	Tr	67	Tr
Daphnia galeata mendotae	1,730	0.6	573	0.7	657	1.5	395	0.2
Daphnia longiremis	90	Tr	4	Tr	1	Tr	36	Tr
Daphnia parvula	0	0.0	0	0.0	*	Tr	*	Tr
Daphnia retrocurva	5,345	2.0	996	1.2	499	1.1	1,077	0.6
Daphnia schodleri	0	0.0	0	0.0	0	0.0	*	Tr
Diaphanosoma brachyurum	0	0.0	1	Tr	0	0.0	*	Tr
Diaphanosoma leuchtenbergianum	0	0.0	1	Tr	0	0.0	*	Tr

Table 4.1. (continued)

	22 September		19 October		16 November		1976 Yearly Mean	
	No./m^3	%	No./m^3	%	No./m^3	%	No./m^3	%
Disparalona rostrata	*	Tr	0	0.0	0	0.0	*	Tr
Eubosmina coregoni	1,953	0.7	1,439	1.8	315	0.7	593	0.3
Eurycerus lamellatus	0	0.0	0	0.0	0	0.0	*	Tr
Holopedium gibberum	543	0.2	72	0.1	41	0.1	82	Tr
Ilyocryptus acutifrons	0	0.0	0	0.0	0	0.0	*	Tr
Ilyocryptus spinifer	0	0.0	0	0.0	0	0.0	*	Tr
Leptodora kindtii	19	Tr	2	Tr	0	0.0	3	Tr
Leydigia leydigi	2	Tr	0	0.0	0	0.0	*	Tr
Macrothrix laticornis	0	0.0	0	0.0	0	0.0	*	Tr
Polyphemus pediculus	10	Tr	1	Tr	0	0.0	1	Tr
Total Cladocera	57,688	21.1	11,376	14.0	2,590	5.9	13,616	7.4
Rotifera								
Anuraeopsis	0	0.0	0	0.0	0	0.0	17	Tr
Ascomorpha	445	0.2	38	0.1	19	Tr	217	0.1
Asplanchna	2,542	0.9	433	0.5	18	Tr	384	0.2
Bdelloid rotifers	19	Tr	20	Tr	2	Tr	17	Tr
Brachionus	9	Tr	3	Tr	4	Tr	19	Tr
Cephalodella	9	Tr	9	Tr	2	Tr	29	Tr
Chromogaster	200	0.1	5	Tr	1	Tr	92	0.1
Collotheca	1,626	0.6	1,094	1.3	419	1.0	660	0.4
Colurella	0	0.0	0	0.0	0	0.0	4	Tr
Conochilus	7,800	2.9	4,851	6.0	409	0.9	1,666	0.9
Dicranophorus	4	Tr	0	0.0	0	0.0	3	Tr
Encentrum	0	0.0	4	Tr	3	Tr	4	Tr
Euchlanis	14	Tr	2	Tr	1	Tr	15	Tr
Filinia	18	Tr	21	Tr	17	Tr	149	0.1
Gastropus	681	0.3	138	0.2	48	0.1	950	0.5
Kellicottia	826	0.3	644	0.8	903	2.1	5,142	2.8
Keratella	27,723	10.2	14,435	17.7	21,005	47.7	27,117	14.7
Lecane	0	0.0	0	0.0	1	Tr	1	Tr
Lepadella	0	0.0	0	0.0	0	0.0	1	Tr
Monostyla	205	0.1	18	Tr	0	0.0	108	0.1
Notholca	28	Tr	31	Tr	344	0.8	6,112	3.3
Notommata	0	0.0	0	0.0	0	0.0	*	Tr
Pleurotrocha	0	0.0	0	0.0	0	0.0	*	Tr
Ploesoma	1,375	0.5	25	Tr	1	Tr	2,144	1.2
Polyarthra	80,521	29.5	23,701	29.1	6,196	14.1	71,317	38.6
Pompholyx	23	Tr	3	Tr	0	0.0	20	Tr
Proales	0	0.0	1	Tr	1	Tr	*	Tr
Synchaeta	48,058	17.6	3,015	3.7	1,027	2.3	28,693	15.5
Trichocerca	3,017	1.1	180	0.2	31	0.1	2,698	1.5
Trichotria	0	0.0	6	Tr	0	0.0	12	Tr
Total Rotifera	175,143	64.0	48,677	59.8	30,452	69.2	147,589	80.0
Total Zooplankton	273,059		81,436		44,017		184,854	

86,000, and 72,000 individuals/m^3, respectively. Numbers increased by a factor of ten in July (to 700,000 individuals/m^3) then declined to the yearly low of about 44,000 individuals/m^3 in November. The secondary maximum of total zooplankton occurred in September and was characterized by high levels of rotifers and copepods and an annual peak in numbers of Cladocera.

Fluctuations in the zooplankton standing crop from April to November were largely responses to changes in rotifer densities since the Rotifera composed at least 60% of the community at all times and were at a maximum of 91% in April (Figure 4.1). In each sampling period either Synchaeta, Polyarthra, or Keratella, was the dominant organism. Synchaeta composed more than 50% of the zooplankton community in April and May while in July Polyarthra composed more than 50%. In the other five months, combinations of the five dominant zooplankters (the three rotifers, Bosmina longirostris and copepod nauplii) composed at least half of the zooplankton.

There was no sampling period in 1976 when a crustacean taxon became the most numerous member of the Kewaunee zooplankton community since the zooplankton was dominated by the Rotifera (Figure 4.1). During the late summer and fall, August through October, there was a decrease in total Rotifera with increases in the number of Crustacea, especially cladocerans. Greatest numbers of Cladocera occurred during September (Table 4.1; Figure 4.1).

The yearly maximum of total zooplankton in July corresponded to high densities in the Copepoda.

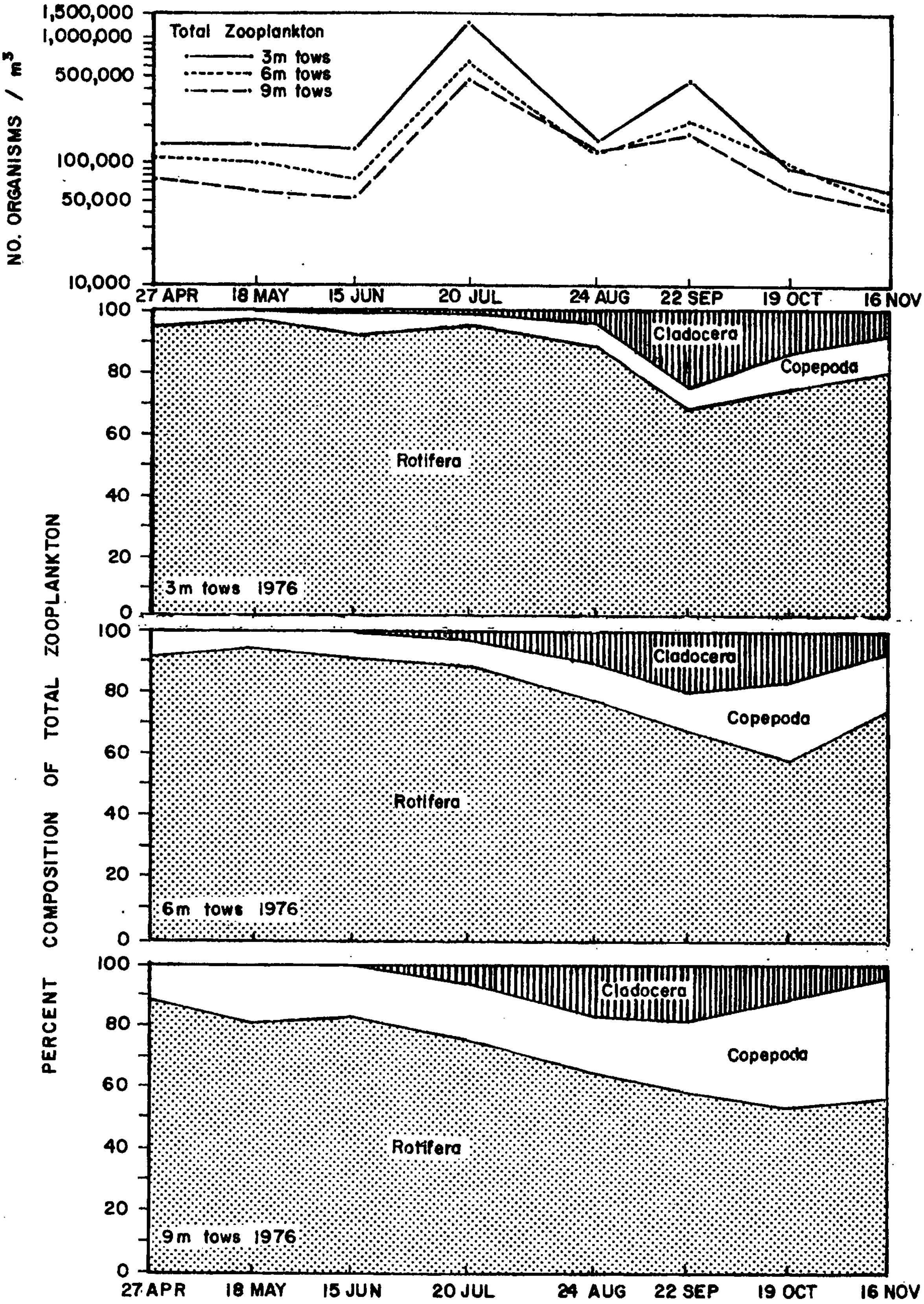

Figure 4.1. Mean density of total zooplankton and percent composition of major zooplankton groups collected along three depth contours in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

The genus Notholca was diminished in numerical importance at Kewaunee and other locations near the shore in Western Lake Michigan waters during 1976 compared to 1975 (Dvorak, personal communication); thus, Notholca cannot be treated as dominant in 1976. Early warm weather and a continuously hot summer may have shortened the seasonal dominance of Notholca which, near shore, is primarily a winter genus (Stemberger 1973, Schar 1974).

The onshore-offshore concentrations of the zooplantkon reflected the spatial distribution pattern of the major groups (Figure 4.1). Total rotifers were always more numerous at the 10 ft contour (3 m tow) than at the 20 ft (6 m tow) or 30 ft (9 m tow) contours. As a result, total zooplankton densities were greatest at the 10 ft contour in all months except October. The three dominant rotifer genera were most concentrated at the 10 ft contour during their periods of peak abundance as were the subdominants Ploesoma and Trichocerca.

The contrast between onshore and offshore densities was not as great in the Copepoda as in the Rotifera, but copepod densities were usually greatest at the 30 ft contour. The Cladocera presented a mixed picture relative to onshore-offshore distribution but during the September peak, the density near shore was nearly four times greater than at 30 ft (9 m tow).

Species diversity values (H') ranged between 0.84 and 3.35 throughout the survey (Table 4.2). Diversity values followed a cyclical pattern that was heavily influenced by the depth contour. At the 10 ft contour the mean diversity values were highest

Table 4.2. Summary of species diversity (H'), maximum possible diversity (H-max), and redundancy (R) for zooplankton collected at fifteen locations in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

	3-Meter Locations					6-Meter Locations					9-Meter Locations				
	2	6	11	15	20	3	7	12	16	21	4	8	13	17	22
27 April															
H'	1.26	1.22	1.20	1.19	1.18	1.53	1.45	1.17	1.23	1.26	1.42	1.51	1.41	1.48	1.37
H-max	4.46	4.09	4.32	4.17	3.91	4.70	4.64	4.59	4.46	4.25	4.91	4.64	4.59	4.70	4.25
R	0.72	0.70	0.72	0.71	0.70	0.67	0.69	0.74	0.72	0.70	0.71	0.67	0.69	0.69	0.68
18 May															
H'	1.19	0.95	1.19	1.64	1.50	1.42	1.07	0.84	1.19	1.11	1.25	2.13	1.51	1.72	1.70
H-max	4.09	3.91	4.00	4.00	4.09	4.46	4.00	4.39	4.32	4.39	4.59	4.25	4.00	4.52	4.25
R	0.71	0.76	0.70	0.59	0.63	0.68	0.73	0.81	0.72	0.75	0.73	0.50	0.62	0.62	0.60
15 June															
H'	2.65	2.46	2.61	2.37	2.07	2.47	2.55	2.57	2.13	2.04	2.33	2.21	2.41	2.20	2.28
H-max	3.81	4.52	4.81	4.64	4.46	4.52	4.52	4.75	4.39	4.81	4.52	4.00	4.52	4.09	4.46
R	0.30	0.46	0.46	0.49	0.54	0.45	0.44	0.46	0.51	0.58	0.49	0.45	0.47	0.46	0.49
20 July															
H'	1.48	1.41	1.39	1.55	1.09	1.99	1.79	1.71	2.02	1.75	2.16	2.22	2.17	2.42	2.07
H-max	4.91	4.64	5.36	4.59	4.64	4.75	5.00	4.70	4.75	4.81	4.81	4.81	4.70	4.64	4.52
R	0.70	0.70	0.74	0.66	0.77	0.58	0.64	0.64	0.58	0.64	0.55	0.54	0.54	0.48	0.54
24 August															
H'	2.13	2.19	2.43	2.15	1.80	2.25	2.46	2.28	2.37	2.00	2.38	2.73	2.77	2.68	2.23
H-max	4.64	4.46	5.25	5.04	4.46	4.86	5.00	4.81	5.00	4.46	4.59	5.17	5.00	5.21	4.81
R	0.54	0.51	0.54	0.57	0.60	0.54	0.51	0.53	0.53	0.55	0.48	0.47	0.45	0.49	0.54
22 September															
H'	2.46	2.40	2.40	2.27	2.21	2.53	2.57	2.29	2.79	2.57	3.12	3.35	2.48	3.01	3.13
H-max	5.25	5.00	5.36	5.04	5.13	4.81	5.09	5.21	5.21	5.32	5.04	5.00	5.13	5.04	5.25
R	0.53	0.52	0.55	0.55	0.57	0.47	0.49	0.56	0.46	0.52	0.38	0.33	0.52	0.40	0.40
19 October															
H'	2.93	2.42	2.26	2.08	2.13	3.12	2.57	2.53	2.25	2.51	2.69	2.96	2.86	2.69	2.40
H-max	5.17	4.95	5.09	4.81	4.86	5.04	4.86	4.91	4.81	5.04	4.86	4.75	5.04	4.91	5.00
R	0.43	0.51	0.56	0.57	0.56	0.38	0.47	0.49	0.53	0.50	0.45	0.38	0.43	0.45	0.52
16 November															
H'	1.95	1.69	2.18	2.19	2.03	2.12	2.00	1.97	2.36	1.97	2.11	2.45	2.46	2.30	2.39
H-max	4.75	4.81	4.59	4.64	4.59	4.75	4.64	4.52	4.59	4.52	4.63	4.81	4.70	4.75	4.75
R	0.59	0.65	0.52	0.53	0.56	0.55	0.57	0.56	0.49	0.56	0.5	0.49	0.48	0.52	0.50

in June, dropped in July, then stayed above 2.00 from August through November with a secondary maximum in October. Values at the 20 ft contour were similar to the locations near shore except that fall diversities rose above those of June and reached a maximum in October. At the 30 ft contour, diversity declined by less than 0.01 points after June and reached a peak in September. June was the only sampling period when the 10 ft and 20 ft contour diversity values exceeded the one at the 30 ft contour.

C. The 1976 Zooplankton Community

1. Rotifera

The combined densities of Polyarthra, Synchaeta, Notholca, and Keratella composed more than 80% of the rotifer population in every month of the study (Figure 4.2). The April and May plateau in total rotifers was supported by the dominance of Synchaeta. In June increasing numbers of Polyarthra mitigated the effect of declining Synchaeta, thus populations of Rotifera were kept high. The July maximum in total Rotifera corresponded to maxima in Polyarthra, Keratella Kellicottia, and Trichocerca, all of which declined in August. The September peak in total rotifers was reflective of maxima for Polyarthra and Synchaeta. In November the dominant, Keratella, was increasing particularly near the shore thus, the late fall decline in total Rotifera was least precipitous at the 10 ft contour.

Polyarthra exhibited its yearly maximum at all three depth contours in July but continued to dominate the rotifers and the total zooplankton through the August, September, and October

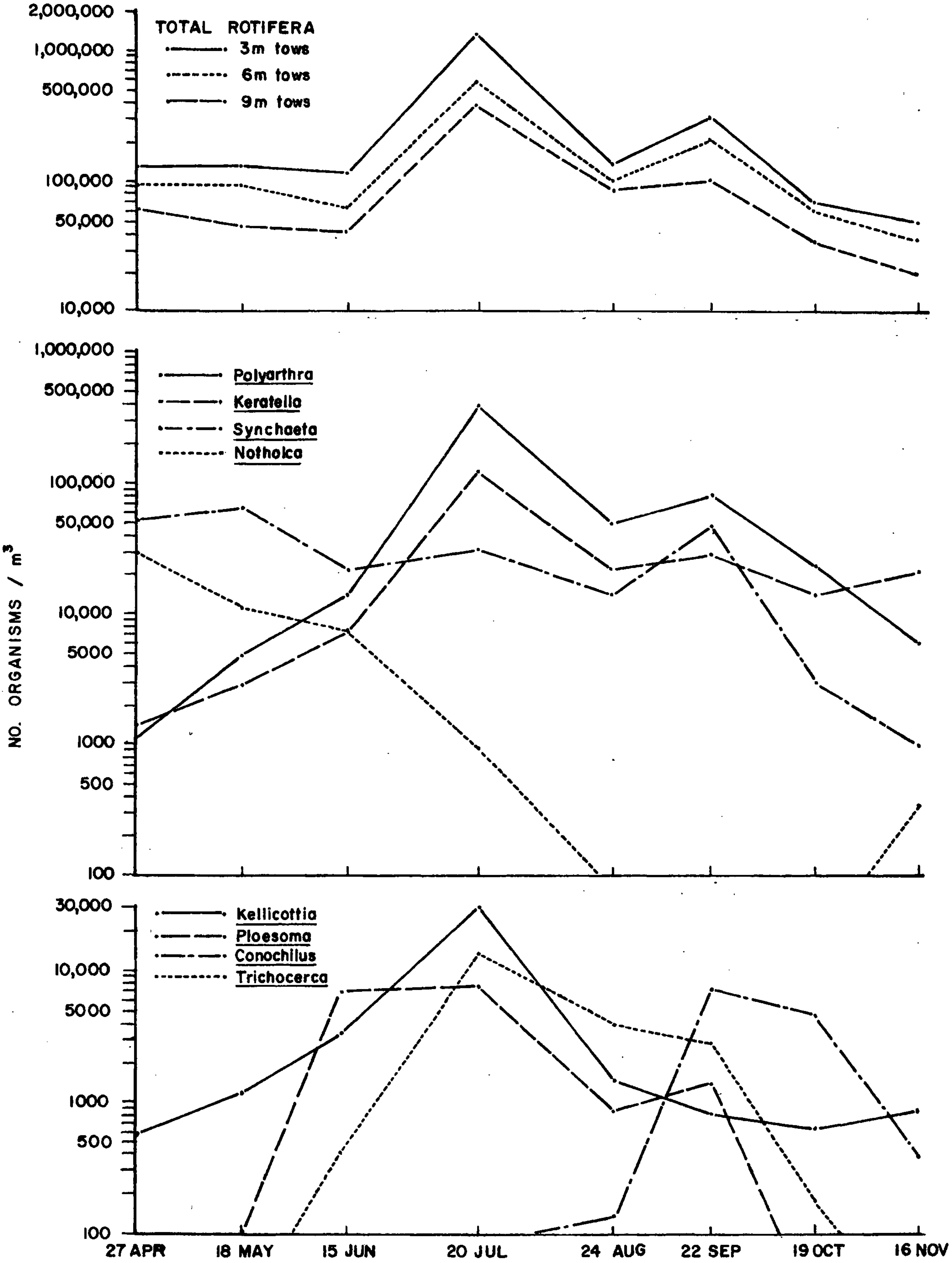

Figure 4.2. Mean density of total Rotifera collected along three depth contours and weighted means of all locations for major rotifer genera collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

sampling periods. Polyarthra populations were most dense at the contour near shore in every month except August. The August decrease in total zooplankton populations coincided with a homogeneou distribution of Polyarthra among depth contours and a drop in the mean density of Polyarthra.

Synchaeta abundances were above 10,000/m^3 from April through September. Densities were greatest at the 10 ft contour during every month but the onshore-offshore populations of Synchaet never diverged widely.

Keratella densities were less than 10,000/m^3 throughout April, May, and June. The low spring values were followed by a pronounced increase (by a factor of 16) to the yearly maximum in July. This maximum was followed by a decline until November when Keratell increased and was the most numerous rotifer and zooplankter in the Kewaunee sampling area.

Among the subdominant rotifers, Ploesoma, as the most numerous zooplankter at Locations 6, 11, and 12 in June, was the only genus to locally and briefly dominate the zooplankton assemblage. In other seasons and at most locations Ploesoma composed a trace to 2% of the total zooplankton. Kellicottia always composed more than a trace of the total zooplankton, ranging up to 5% of the total. However, Kellicottia never dominated the zooplankton assemblage and, during its maximum occurred at greater densities at the 30 ft contour than near shore. Trichocerca and Conochilus were temporarily numerous but persistent at low densities at Kewaunee in 1976. The effect of Trichocerca on total rotifer densities was not great because its population maximum occurred near shore simultaneous with those of much more numerous genera. In September and October Conochilus ranged between 21.7% and 0.4% of the total Rotifera.

2. Copepoda

All life stages of the Copepoda were observed in the study area including nauplii (larvae), calanoid and cyclopoid copepodites (juveniles) and adults (Figure 4.3). Nauplii were by far the most numerous component of the Copepoda and ranged from 90% to 21%. Nauplii was also the most homogeneous zooplankton taxon in regard to onshore-offshore distribution with densities never differing by a factor greater than 3 among the three depth contours.

The onshore-offshore distribution of Copepoda was homogeneous compared to Rotifera and Cladocera but almost all components of the Copepoda occurred at greater density in deeper water. Epischura lacustris was an exception to this in November when its population near the shore was 780 organisms/m^3 compared to 100/m^3 offshore.

Maximum populations of Copepoda occurred in July and coincided with maxima among nauplii and calanoid copepodites. Large copepod populations were present in September due to high numbers among all the copepods.

Cyclops bicuspidatus thomasi, Diaptomus ashlandi Tropocyclops prasinus mexicanus, D. oregonensis, and D. minutus were numerically the most important species of adult Copepoda and appeared in every month of the study. Strong seasonal appearances

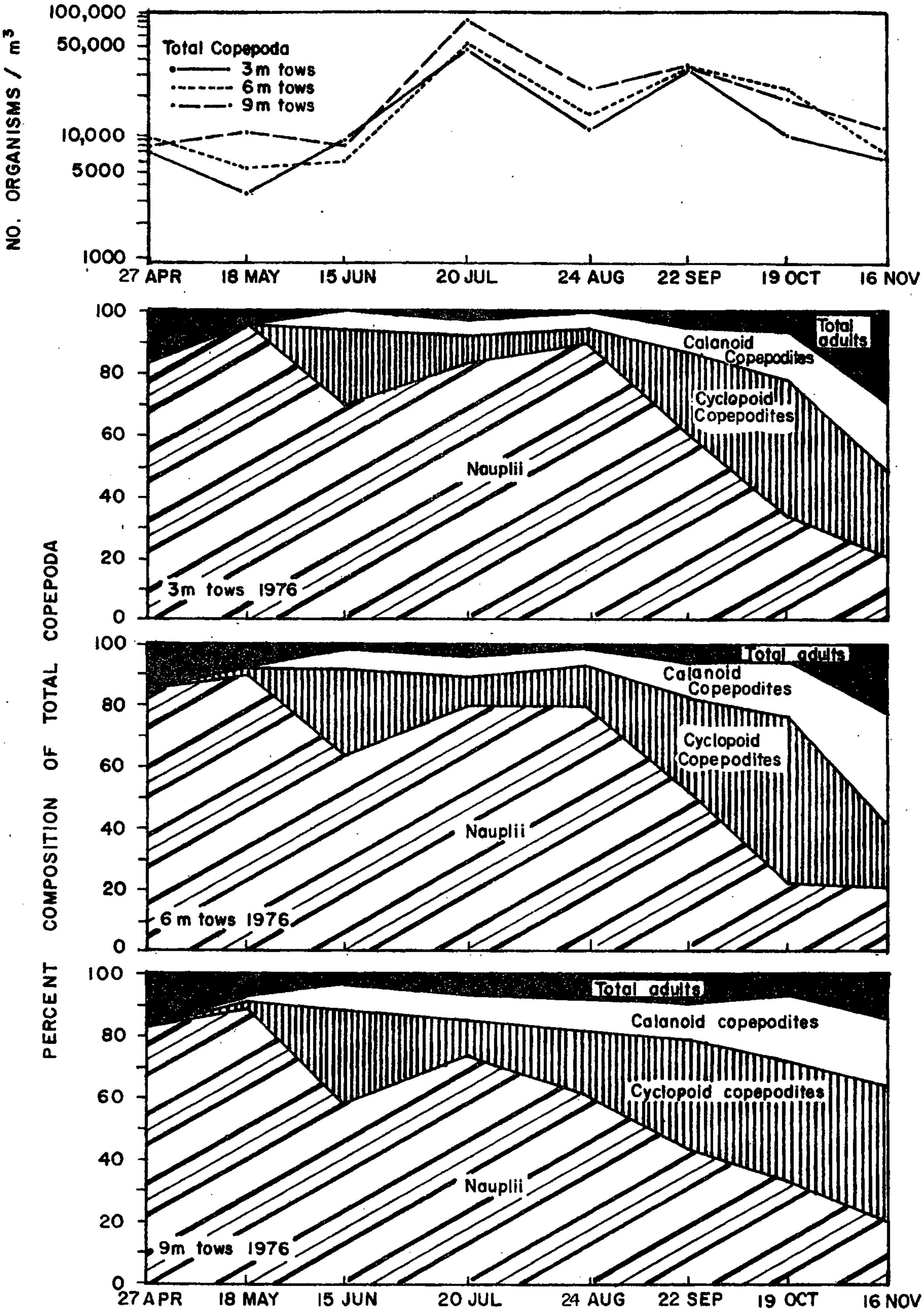

Figure 4.3. Mean density and composition of total Copepoda collected along three depth contours in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 197

were made by Epischura lacustris and Mesocyclops edax. In November E. lacustris composed more than 1/3 of the total adult copepods at the 10 ft contour.

Cyclops bicuspidatus thomasi was the most common adult copepod throughout the sampling period (Figure 4.4). The lowest density of C. b. thomasi occurred in June and the highest in July with its seasonal patterns being similar to the pattern observed in 1973, 1974, and 1975. Densities declined from April to extremely low numbers in early summer. This seems to have been an inshore effect, as early summer populations remained higher at the 30 ft contour. The population was maximum in mid-summer, and smaller, but stable through the fall.

In April and November the onshore-offshore densities of C. b. thomasi were homogeneous and in October they were highest at the 20 ft contour; but, in every other month of the 1976 sampling period, densities were greatest offshore. The comparative sparseness of the population near shore was most noticeable in August and May when densities near the shore were only 6 and 9% of the densities offshore, respectively. In early spring when the population of C. b. thomasi was high, the male to female ratio was approximately 0.6. As the population declined, the adult females disappeared almost entirely so that during the July peak males were 2 or 3 times more common than females. The sex ratio was closer to 1 from September through November.

The highest densities of total Diaptomus spp. for 1976 occurred in April and November while the summer maximum was

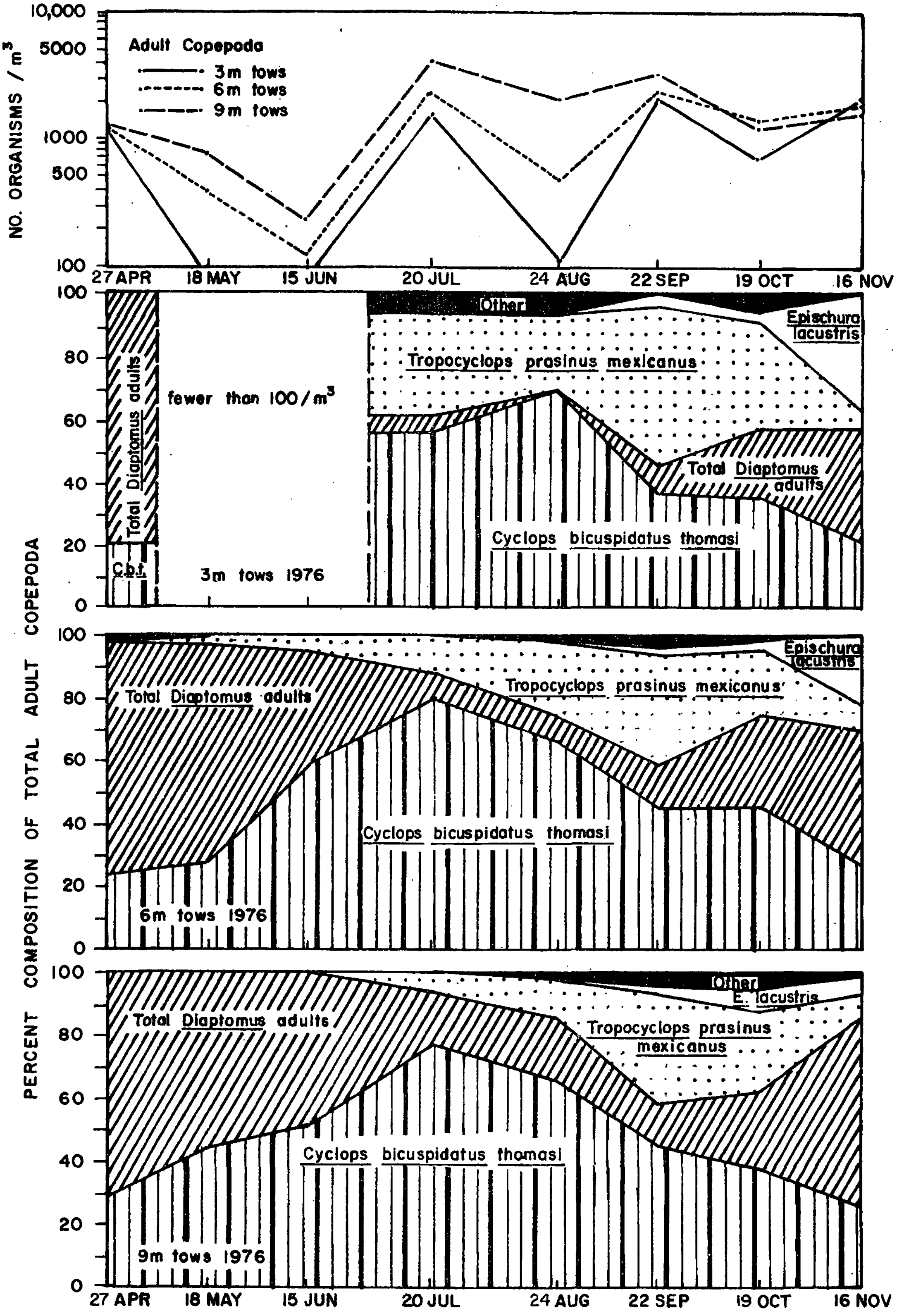

Figure 4.4. Mean density and composition of Adult Copepoda collecte
along three depth contours in Lake Michigan near the
Kewaunee Nuclear Power Plant, April through November 197

much reduced when compared to that of 1975. As a result, only half as many Diaptomus were observed this year as in 1975. Densities at the offshore contour were relatively high and stable throughout the study except for the yearly minimum in June. Much greater fluctuations in the populations of Diaptomus were found at the 10 and 20 ft contours, and in August the genus nearly disappeared from the 10 ft contour.

Diaptomus ashlandi was the most abundant adult diaptomid, which was not unusual since it is known as a more littoral species than D. oregonensis, D. minutus, or D. sicilis, and has been the most numerous diaptomid in previous years. The yearly population maximum for D. ashlandi occurred in July at which time D. ashlandi composed 89% of the total Diaptomus adults.

More than twice as many Tropocyclops prasinus mexicanus appeared in the 1976 study as in 1975 or 1974. A strong population appeared in July, maximized in September and remained higher than $100/m^3$ through November. During the September maximum, offshore populations were slightly higher than those near the shore. The July population was greatest at the 10 ft contour, and throughout the fall density was homogeneous.

3. Cladocera

The total Cladocera was strongly dominated by Bosmina longirostris (Figure 4.5) which composed from 40% to 99% of the Cladocera except for one instance in November when it represented 20% of the Cladocera at the 30 ft contour.

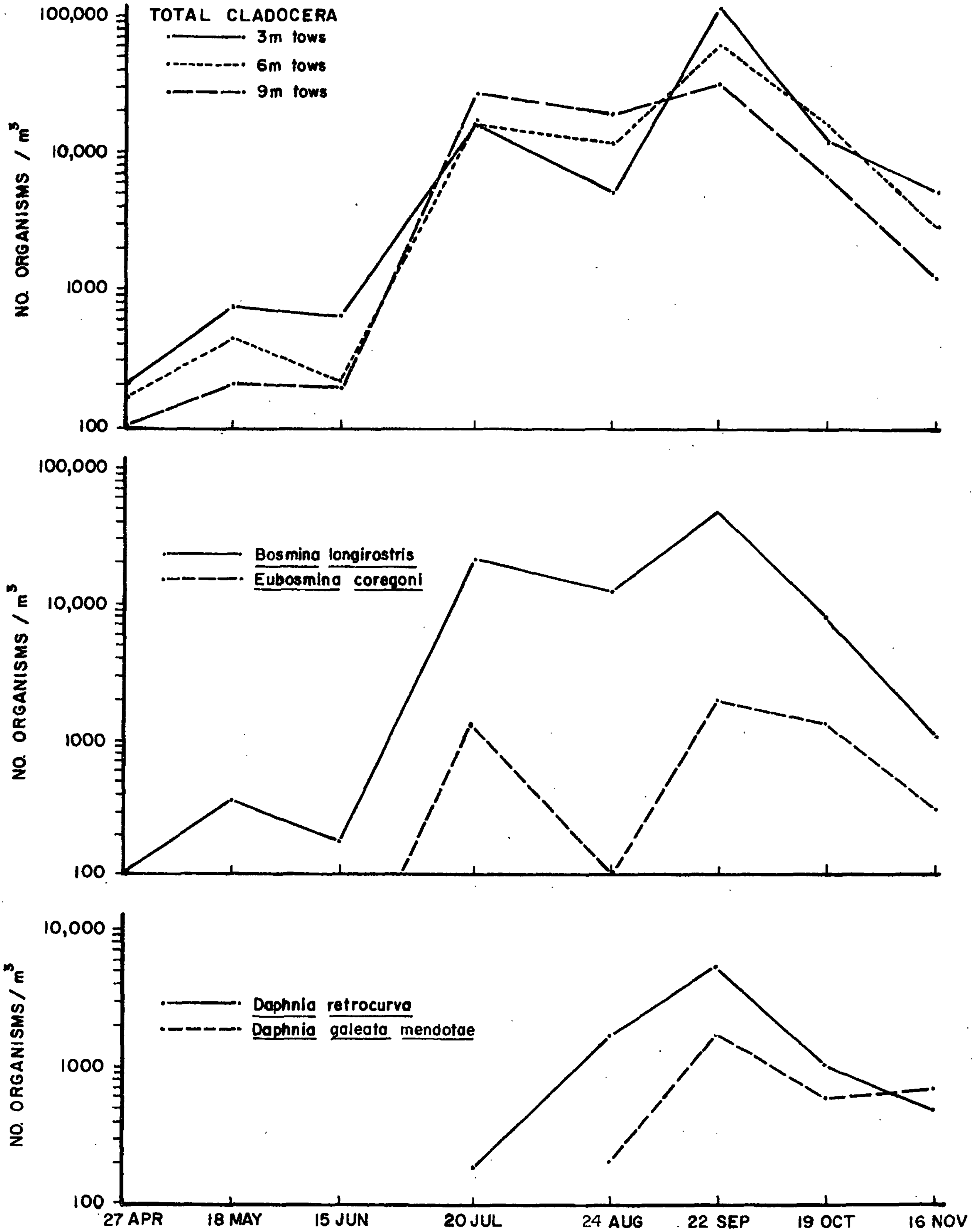

Figure 4.5. Mean density of total Cladocera collected along three deptl contours and weighted means of all locations for major cladoceran species collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

The yearly mean density of the B. longirostris population in 1976 was approximately 1.25 times greater than 1974 and 1.33 times greater than 1975. Maxima occurred in July and September, but the population remained high in August. Virtually all of the specimens observed during the summer were parthenogenic females while after September a large number of males and ephippial females appeared in the declining population. The density of B. longirostris was substantially greater near the shore than offshore in every month except July and August.

The Eubosmina coregoni population was three times greater in 1976 than in the two previous years. Maxima occurred in July and September with a very low population in August. After the September maximum the population declined slowly but was still quite numerous in November. E. coregoni was always more dense in deeper water than at the 10 ft contour.

Daphnia retrocurva was absent or appeared only as a trace until August. When D. retrocurva was at a maximum (September) it composed only 2% of the zooplankton community. The population declined through October and November both in percent composition and density. November was the only month when D. retrocurva was most numerous near the shore, and in the same period the male and female ratio was highest, particularly near the shore.

The population of Daphnia longiremis was much smaller in 1976 compared to 1975. Mean densities greater than 100/m^3 appeared only in July.

Daphnia galeata mendotae was much more numerous this year than in the two previous years. Densities above 100/m^3 appeare throughout the latter half of the sampling period. Population density was heavily weighted offshore in August, was homogenous in September and October, and was most numerous inshore in November. A substantial number of males was present in the population from September through November.

Three other cladoceran populations exhibited a monthly mean density greater than 100/m^3: Chydorus gibbus, C. sphaericus, and Holopedium gibberum. Chydorus gibbus, whose population has been very small in previous years, occurred in substantial numbers near the shore for three consecutive months: July through September. Several males of C. gibbus were seen before the population disappeared in November. Chydorus sphaericus usually appears in substantial numbers and this year it appeared in every month of the study. Chydorus sphaericus lives among the periphyton, becomin pelagic if planktonic algae are present (Smirnov 1971); thus, many specimens were observed inshore in July and August, but in Septembe when the monthly mean was highest, the onshore-offshore distributio was homogeneous.

Holopedium gibberum was twice as numerous this year as in 1975. The population of H. gibberum was greater than 300/m^3 at all three depth contours in September. Several males were spotted in November.

D. Localized Variations in the Zooplankton Community

Total zooplankton densities for each of the five sampling locations on three depth contours are presented for every sampling

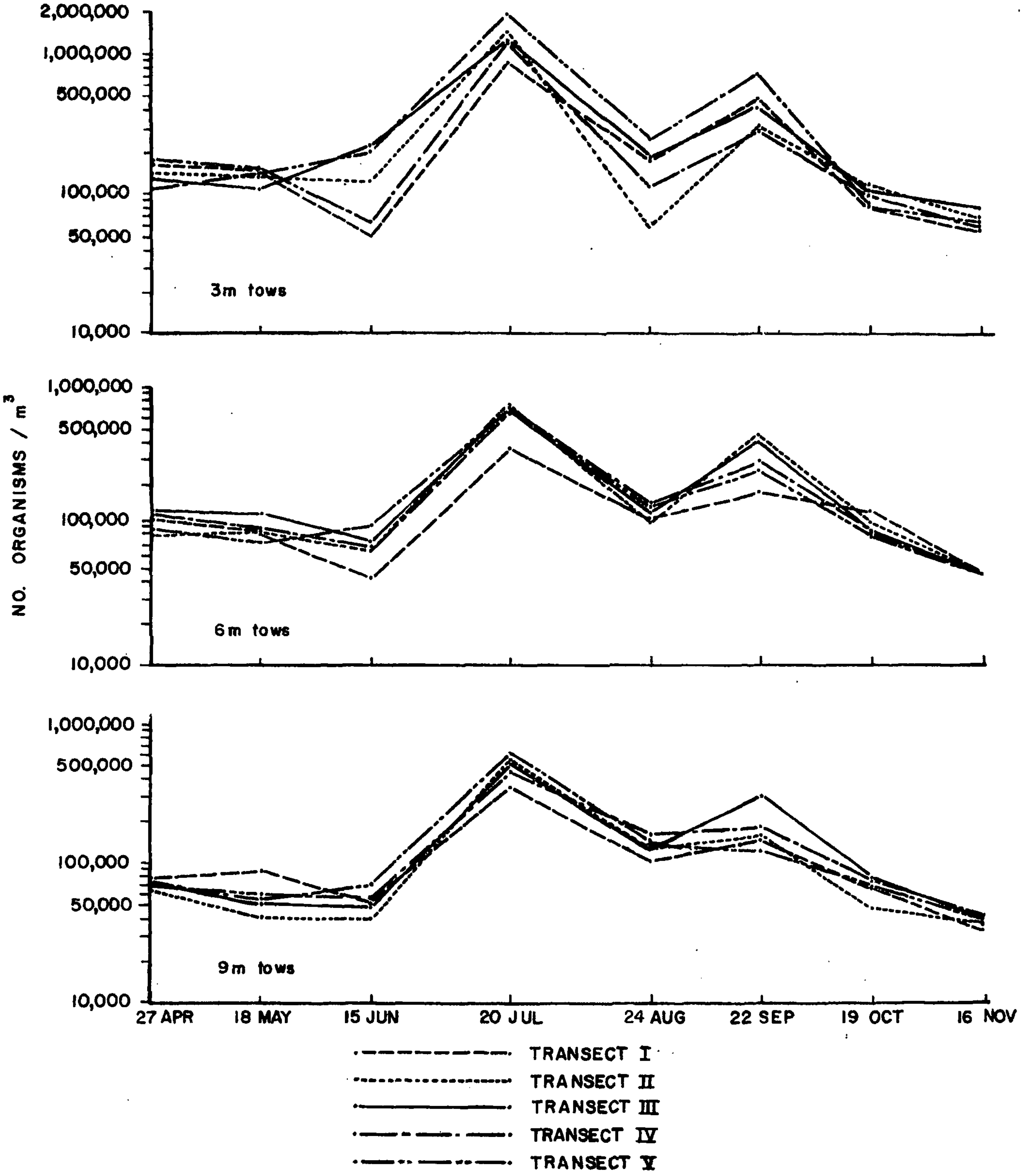

Figure 4.6. Density of total zooplankton collected at fifteen locations along 10 ft, 20 ft and 30 ft contours in Lake Michigan near Kewaunee Nuclear Power Plant, April through November 1976.

whether significant differences existed among locations in the same depth contour. In order to obtain valid results densities had to b substantial, usually greater than 100 organisms/m^3, and have a smal standard error. Differences that were significant at the probability $P \leq 0.05$ level were detected in every sampling period (Table 4.3)

Only those significant differences which include Transect III (Locations 11, 12 and 13) will be discussed. Location 11 was in the thermal plume on every sampling date in 1975, while Location 12 was in the plume for six and Location 13 for three of the eight sampling dates (Urry 1976). Thermal plume mapping was not done in 1976; therefore, the nature of the 1976 thermal plumes cannot be defined, only inferred.

No total zooplankton abundances were significantly different for the inshore contours (Table 4.3). This would imply that within the zooplankton community there were no consistent population trends. In fact, it was only during four months; June, August October, and November, that more than 10% of the zooplankton taxa a Location 11 were significantly different from another location near the shore. This accounted for the lack of consistent trends in the total community.

The tests on taxa collected at the 20 ft contour, likewise, did not reveal consistent trends. Zooplankton abundances at the 20 ft contour in September were significantly greater at Location 12 than at Location 3, but no specific taxon tested yielde similar results (Table 4.3).

Table 4.3. Summary of multiple comparison tests following the Kruskal-Wallis nonparametric ANOVA for abundance of major zooplankton taxa collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

	Depth of Tow (meters)	Significant Differences Among Transects							
		April	May	June	July	August	September	October	November
Copepoda									
nauplii	3	nd[a]	ns	III>IV	V>I	I>II	nd	II>V	nd
	6	nd	ns	ns	IV>I	ns	II>I	II,I>V	ns
	9	ns[b]	II>III	IV>III	V,IV>I	IV>V	ns	III>V,IV	II>I
calanoid copepodites	3	nt[c]	nt	nd	V>I	III>II	ns	I>V	nd
	6	nt	nt	ns	II>III	ns	IV,II>I	I>V	IV>III
	9	nt	nt	IV>III	IV>III	IV>V	nd	nd	II,III>I
cyclopoid copepodites	3	nt	nt	III,II>V	nd	nd	nd	II,I>V	IV>III
	6	nd	nt	I>V	V>III	IV>V	II>I	I>V	nd
	9	nt	nt	nd	II>I	nd	nd	III,I>IV	III>I
Cyclops bicuspidatus thomasi	3	ns	nt	nt	IV>I	nt	I>IV	I>V	nd
	6	nd	nt	nt	nd	II>V	II>III	I,II>V	nd
	9	nt	nt	nt	nd	IV>V	II>III	ns	nd
Diaptomus ashlandi	3	nd	nt	nt	nt	nt	ns	nd	nt
	6	ns	nt	nt	nt	nt	nd	I>V	ns
	9	nt	nt	nt	IV>I	IV>V	ns	ns	nt
Diaptomus oregonensis	3	ns	nt	nt	nt	nt	nt	nt	nd
	6	ns	nt	nt	nt	nt	nt	nt	ns
	9	nt	nt	nt	nt	ns	ns	ns	ns
Epischura lacustris	3	nt	nt	nt	nt	nt	nt	nt	III>II
	6	nt	nt	nt	nt	nt	nd	nt	nd
	9	nt	nt	nt	nt	nt	ns	nd	ns
Mesocyclops edax	6	nt	nt	nt	nt	nt	nd	nt	nt
	9	nt	nt	nt	nt	nt	ns	I>IV	nt
Tropocyclops prasinus mexicanus	3	nt	nt	nt	nd	nt	III>IV	I>V	ns
	6	nt	nt	nt	nd	nd	nd	V>II,IV	nd
	9	nt	nt	nt	nd	ns	ns	ns	nd
Total Copepoda	3	nd	ns	nd	V>I	III,I>II	nd	II>V	IV>II
	6	nd	ns	ns	IV,V>I	nd	II>I	I,II>V	nd
	9	ns	II>III	IV>III	V,IV>I	IV>V	nd	III>IV,V	III>I
Cladocera									
Bosmina longirostris	3	ns	nt	nt	ns	III>II	V>IV	II>III	nd
	6	ns	nt	nt	nd	V>I	II>I	nd	I>IV
	9	nt	nt	nt	V>I	V>I	III>V	IV>III,II	V>I
Chydorus sphaericus	3	nt	nt	nt	ns	nt	nt	nt	nt
	6	nt	nt	nt	nd	nt	nt	nt	nt
	9	nt	nt	nt	ns	nt	V>I	nt	nt

Table 4.3. (continued)

	Depth of Tow (meters)	Significant Differences Among Transects							
		April	May	June	July	August	September	October	November
Daphnia galeata mendotae	3	nt	nt	nt	nt	nt	nd	I>V,IV	III>II,I
	6	nt	nt	nt	nt	nt	IV>III	I>V	nd
	9	nt	nt	nt	nt	IV>I	nd	ns	V>III
Daphnia retrocurva	3	nt	nt	nt	nt	III>II	ns	I>V	ns
	6	nt	nt	nt	nt	IV>I	II>III	I>V	ns
	9	nt	nt	nt	nd	nd	IV,II>III	III>V	nd
Eubosmina coregoni	3	nt	nt	nt	ns	nt	ns	I>V	ns
	6	nt	nt	nt	nd	nt	V,IV>I	I>V	ns
	9	nt	nt	nt	nd	II>V	II>III	nd	nd
Hdopedium gibberum	3	nt	nt	nt	nt	nt	I>V	nt	nt
	6	nt	nt	nt	nt	nt	ns	I>V	ns
	9	nt	nt	nt	nt	nt	II>III	ns	nd
Total Cladocera	3	ns	nt	nt	III>V	III>II	V>IV	II>IV	III>I
	6	ns	nt	nt	nd	V>I	II>I	nd	ns
	9	nt	nt	nt	V>I	V>I	III>V	IV>II	nd
Rotifera									
Ascomorpha spp.	9	nt	nt	nt	nt	nd	nt	nt	nt
Asplanchna spp.	3	nt	nt	nt	nt	nt	I>II	nd	nt
	6	nt	nt	nt	nt	nt	nd	nd	nt
	9	nt	nt	nt	nt	nt	ns	nd	nt
Cephalodella spp.	3	nt	nt	III>I	nt	nt	nt	nt	nt
Collotheca spp.	3	nt	nt	nt	nt	ns	II>IV	ns	ns
	6	nt	nt	nt	nt	ns	ns	ns	ns
	9	nt	nt	nt	nt	ns	ns	ns	ns
Conochilus spp.	3	nt	nt	nt	nt	nt	I>III	nd	ns
	6	nt	nt	nt	nt	ns	nd	I>IV	ns
	9	nt	nt	nt	nt	nt	IV>III	IV>I	ns
Gastropus spp.	6	nt	nt	nt	nd	nt	nt	nt	nt
	9	nt	nt	nt	ns	nt	nt	ns	nt
Kellicottia spp.	3	ns	ns	ns	II>III	ns	ns	ns	ns
	6	ns	ns	nd	IV>I	ns	ns	ns	ns
	9	ns	ns	V>II	nd	nd	ns	ns	ns
Keratella spp.	3	ns	nd	V>I	II>I	V>II	ns	nd	ns
	6	ns	nd	nd	II>I	III>V	II>I	II>I	ns
	9	ns	ns	V>IV	III>I	ns	III>V	III>II	nd
Monostyla spp.	3	nt	nt	nt	nt	nd	nt	nt	nt
	6	nt	nt	nt	nt	ns	nt	nt	nt

Table 4.3. (continued)

	Depth of Tow (meters)	Significant Differences Among Transects							
		April	May	June	July	August	September	October	November
Notholca spp.	3	nd	IV>V	III>I	nt	nt	nt	nt	ns
	6	ns	I>V	nd	ns	nt	nt	nt	ns
	9	ns	nd	I>II	nd	nt	nt	nt	ns
Ploesoma spp.	3	nt	nt	III>IV	V>II	nd	ns	nt	nt
	6	nt	nt	nd	II>I	ns	ns	nt	nt
	9	nt	nt	nt	ns	ns	ns	nt	nt
Polyarthra spp.	3	ns	IV>II	V>I	V>I	V>II	V>II	nd	nd
	6	ns	nd	V>I	nd	ns	ns	nd	ns
	9	ns	nd	V>IV,II	V>IV	nd	III>II	V>II	ns
Synchaeta spp.	3	ns	ns	V>I	ns	I>IV	V>I	III>I	ns
	6	nd	nd	V>I	nd	ns	III>IV	ns	ns
	9	nd	I>II	ns	nd	nd	III>V	nd	ns
Trichocerca spp.	3	nt	nt	III>IV	V>I	nd	nd	nt	nt
	6	nt	nt	nt	ns	IV>V	nd	nd	nt
	9	nt	nt	nt	V>IV	nd	nd	ns	nt
Total Rotifera	3	nd	ns	V>I	V>I	V>II	ns	nd	ns
	6	ns	ns	V>I	nd	ns	nd	ns	ns
	9	I>II	I>II	V>II	nd	ns	III>V	IV>II	nd
Total Zooplankton	3	nd	ns	nd	V>I	V>II	nd	nd	ns
	6	ns	ns	V>I	nd	ns	II,III>I	ns	ns
	9	ns	I>II	V>II	V>I	nd	III>V	III>II	IV>I

[a] nd = Differences which were significant at $P \leq 0.05$ could not be detected by multiple comparison test.
[b] ns = Nonsignificant at $P<0.05$.
[c] nt = Insufficient abundances for valid statistical testing.

Most abundances of the taxa collected at the offshore (30 ft) contour did not reveal any consistent population trends (Table 4.3). Some statistically significant differences were found during September and October. In both of these months the total zooplankton communities at Location 13 were significantly greater than at another location in the offshore contour (Figure 4.6); i.e. the total zooplankton densities at Location 13 during September (298,159 organisms/m^3) were greater than those at Location 22 (117,536 organisms/m^3). Three of the dominant organisms, Bosmina longirostris, Keratella and Synchaeta, were significantly more abundant at Location 13 than at Location 22. Combined differences among the three were 130,000 organisms/m^3, 33% of the community, and accounted for the total zooplankton population difference.

During October the densities of the zooplankton community at Location 13 (74,555 organisms/m^3) were significantly greater tha at Location 8 (46,050 organisms/m^3). Keratella which represented 16% of the zooplankton also showed similar differences in density between Location 13 and 8 (Table 4.1).

Further examination of the significant results found in these months showed the profound patchiness so characteristic of plankton life. Significant differences between transects were foun but consistent abundance trends were not distinct in any of the months for any depth contour except the densities at the 30 ft contour during September and October. These two trends of increased populations at Location 13 cannot be solely or directly defined as an effect caused by the thermal plume. It is important to note tha when the thermal plume characteristics were defined in the 1975 sampling Location 13 was within the plume's boundaries only three times during the 1975 sampling year. Therefore, the two distinct density trends observed in 1976 may be purely a function of plankton patchiness.

IV. Summary and Conclusions

1. Eighty-two zooplankton taxa were observed near KNPP, five of which had not been observed in the study area during previous studies. All of the newly sighted taxa were rarely encountered and did not constitute a significant change in community structure from previous studies.

2. The zooplankton community expressed the yearly maximum in July and a secondary maximum in September.

3. Rotifera ranged from 60% to 91% of the zooplankton density and, therefore, trends among total zooplankton were usually a reflection of trends among Rotifera.

4. Three or less taxa always constituted 47% of the zooplankton mean density for each month. This dominance pattern was caused by five taxa: *Keratella* spp., *Polyarthra* spp., *Synchaeta* spp., *Bosmina longirostris*, and cyclopoid copepodites.

5. In a location by location survey in each month, one of the five major taxa was always dominant except for a unique situation at Locations 6, 11, and 12 in June. On that occasion the sub-dominant rotifer *Ploesoma* was the most numerous zooplankter.

6. The rotifers *Chromogaster* spp. and *Ascomorpha* spp., whose populations at Kewaunee have heretofore been miniscule, appeared in numbers greater than 200/m^3 for two and three consecutive months, respectively.

7. Zooplankton were generally more dense near shore than at mid- and offshore locations throughout the study.

8. Rotifer populations expressed maxima or high plateaus in response to strong dominance by one of the three major genera.

9. The major copepod taxa were nauplii, calanoid copepodites, cyclopoid copepodites, Cyclops bicuspidatus thomasi, Diaptomus ashlandi, D. minutus, D. oregonensis, and Tropocyclops prasinus mexicanus. The seasonal dynamics among the Copepoda were dominated by the immature forms.

10. The Copepoda expressed their yearly maximum in July, but were present in monthly mean densities greater than 10,000/m^3 from July through November.

11. The major cladoceran taxa were Bosmina longirostris, Daphnia retrocurva, Eubosmina coregoni, D. galeata mendotae. Seasonal dynamics among the Cladocera were dominated by Bosmina longirostris.

12. Cladoceran populations expressed a strong yearly maximum in September, but were very abundant July through October.

13. The cladoceran Chydorus gibbus, whose population at Kewaunee has heretofore been miniscule, appeared in numbers greater than 100/m^3 in July 1976.

14. Significant ($P \leq 0.05$) abundance trends were detected for the 30 ft contour during September and October, but Plant effect could not be defined as the cause.

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NALCO ENVIRONMENTAL SCIENCES

CHAPTER 5

PHYTOPLANKTON PHYSIOLOGY

Darrell G. Redmond

OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR
KEWAUNEE NUCLEAR POWER PLANT

SIXTH ANNUAL REPORT
January - December 1976

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Chapter 5

PHYTOPLANKTON ENTRAINMENT

Darrell G. Redmond

I. Introduction

Phytoplankton physiology studies were performed to assess the physiological impact on planktonic organisms passing through the Plant's condenser cooling water system and entrained in the thermal plume. The immediate and long-term effects of condenser passage and plume entrainment on the phytoplankton community were studied for periods when a measurable ΔT was present at the point of discharge.

The specific objectives of this study were:

1. to assess possible immediate and delayed effects of condenser passage on phytoplankton carbon uptake (an indicator of photosynthetic activity) and chlorophyll *a* concentration (an estimate of biomass and indicator of viability);
2. to assess possible immediate and delayed impact of thermal plume entrainment on phytoplankton carbon uptake and chlorophyll *a* concentrations;
3. to evaluate the impact of condenser passage and plume entrainment on phytoplankton abundance; and
4. to document any changes in phytoplankton species composition occurring as a result of condenser passage and/or plume entrainment.

II. Field and Analytical Procedures

A. Experimental Design

In order to evaluate the effects of condenser passage and thermal plume entrainment on phytoplankton carbon fixation, chlorophyll a concentration, abundance and species composition, a monthly sampling schedule was followed from January through November at the sampling locations described in Table 5.1. During January and February, samples were taken only at Locations E-1 and E-2. However from April through November samples were collected at each of six locations (E-0 through E-5). Samples were collected on the following dates: 27 January, 10 February, 28 April, 25 May, 22 June, 13 July, 24 August, 21 September, 19 October, and 16 November. Sampling was not conducted in March because of Plant shutdown.

This investigation was limited to comparisons of data obtained for the following parameters:

1. phytoplankton abundance and species composition observed at 7 and 72 hours after sample collection (Locations E-0 through E-5 and Locations E-1 and E-2, respectively);
2. phytoplankton carbon fixation rates measured at 7, 24, 48 and 72 hours after collection; and
3. phytoplankton chlorophyll a concentrations measured at 7, 24, 48 and 72 hours after sample collection.

B. Field and Laboratory Procedures

Two composite water samples of 24 liters each were collected from each entrainment study location (Table 5.1) using a 6 liter Kemmerer sampler. All samples were taken from near the

Table 5.1. Description of sampling locations for entrainment studies near the Kewaunee Nuclear Power Plant during 1976.

Sampling Location	Description
E-0	Intake location, 1600 feet offshore near the openings of the intake structure.
E-1	Intake location, in Plant forebay.
E-2	Discharge location, prior to mixing with Lake Michigan.
E-3	Plume location, where the temperature is at the forebay temperature plus 50% of the ΔT.
E-4	Plume location, where the temperature is at the forebay temperature plus 20% of the ΔT.
E-5	Control location, outside the plume (north or south of the plume depending on plume configuration).

surface except at Location E-0 where samples were taken at the depth of the intake structure (16 ft). Each composite sample was placed in a translucent carboy, maintained approximately at intake water temperature and used as the source of phytoplankton samples. From these samples, determinations of chlorophyll a concentrations and rates of carbon fixation were performed at 7, 24, 48 and 72 hours after collection in order to assess possible immediate and delayed effects of entrainment. A 1.9 liter subsample was preserved in "M^3" fixative (Meyer 1971) and used for species identification and enumeration at 7 and 72 hours after collection.

1. Phytoplankton Identification and Enumeration

Identification and enumeration of phytoplankton were determined using the inverted microscope method (Lund, et al 1968; Weber 1973) and 25 ml settling chambers. One transect was made across the counting slide at a magnification of 400 X, and all phytoplankters considered viable (i.e., an intact chloroplast) at the time of fixation were enumerated. Identification of phytoplankton was to the lowest positive taxon with diatoms identified to species only when practical, due to chloroplast obstruction of valve markings. Reporting units of algal forms and taxonomic keys used are contained in Chapter 3, Phytoplankton.

2. Chlorophyll a Concentrations

Three subsamples from each composite water sample were analyzed for chlorophyll a concentration at 7, 24, 48 and 72 hours after collection. Each subsample was filtered through a Whatman GF/C glassfiber filter on a thin layer of $MgCO_3$, eluted for at least 24 hours with 90% actone and subjected to ultrasonic disruption. The subsample was then centrifuged and the fluorescence determined before and after addition of 1 N HCl (Lorenzen 1966). The chlorophyll a concentration in the acetone extract was calculated according to the general equation of Strickland and Parsons (1972) and expressed as milligrams per cubic meter of water (mg Chl a/m^3).

3. Rate of Carbon Fixation

The rate of carbon fixation was estimated with the light-dark bottle ^{14}C method (Parkos et al 1969, Strickland and Parsons 1972, Wetzel 1964). Four 50 ml subsamples (3 light bottles and 1 dark bottle) were taken from each composite water sample at 7, 24, 48 and 72 hours after collection. Each subsample was placed in a 50 ml container, inoculated with 4-5 microcuries of aqueous ^{14}C solution, agitated and incubated in an environmental chamber at ambient lake temperature. Following incubation, the subsample was filtered through a 0.45 μ porosity membrane filter. The filter was dried, exposed to fumes of concentrated HCl for 10 minutes (Wetzel 1965) and placed in low-potassium glass scintillation vials with the algal coating to the inside. Seventeen milliliters of scintillator fluid were added and the activity determined using a Packard Tri-Carb-3385 refrigerated liquid scintillation counter. The rate of carbon fixation was expressed as milligrams of carbon fixed per cubic meter per hour (mg $C/m^3/hr$).

Alkalinity and pH determinations were carried out at 7 and 72 hours after sample collection.

C. Statistical Procedures

A nested one-way analysis of variance and Tukey's multiple comparison procedure were applied to both carbon fixation and chlorophyll *a* data to detect differences between locations for each sampling period. All testing was performed at $P \leq 0.05$.

III Results and Discussion

A. Plant Operating Data

The Kewaunee Nuclear Power Plant (KNPP) was operating at between 75% and 100% (390 to 520 MWE) power capacity during the 1976 sampling periods with power generation equalling or exceeding 98% capacity during 9 of 10 sampling periods (Table 5.2). Two circulating water pumps were in operation from April through November with one in use during January and February. Discharge water temperatures exceeded ambient Lake Michigan water temperatures by a mean of 10.8 C (range of ΔT: 7.5-16.0 C) during 1976. The highest ΔT's occurred during January and February when only one circulating water pump was in service.

B. Entrainment Effects on Phytoplankton

1. Plant Entrainment

A. Immediate Effects (Seven Hours after Sample Collection)

Measurements of phytoplankton carbon fixation rates and chlorophyll a concentrations in discharge (Location E-2) samples relative to measurements made for intake (Location E-1) samples revealed only slight changes in these parameters immediately following condenser passage. Samples from the discharge canal generally exhibited slightly lower carbon fixation rates and chlorophyll a concentrations than samples collected at the forebay (Table 5.3) Exceptions occurred in January, February, April and November when discharge samples had higher carbon fixation rates than forebay samples, and in January and October when chlorophyll a concentrations at the discharge exceeded values measured at the forebay. Significant

Table 5.2. Summary of physical and chemical parameters measured at Kewaunee Nuclear Power Plant, January through November 1976.

	Water Temperatures (°C)										
Date	Intake Pipe E0	Forebay E1	Discharge Canal E2	Plume E3	Plume E4	Control E5	ΔT E2-E1 (°C)	Total Alkalinity (mg/l-$CaCO_3$)	pH	No. Circ. Water Pumps in Operation	% Power Capacity
27 January		0.0	16.0				16.0	112	7.8	1[a]	99
10 February		1.0	17.0				16.0	108	8.0	1	99
28 April	6.0	6.0	13.5	11.0	8.0	6.0	7.5	111	7.7	2	75
25 May	10.5	10.5	19.5	15.5	12.5	10.5	9.0	113	8.2	2	98
22 June	9.0	8.0	18.0	13.0	11.0	10.0	10.0	110	8.0	2	99
13 July	14.5	15.5	25.5	20.5	17.5	15.8	10.0	111	7.8	2	100
24 August	17.5	17.3	26.5	22.0	19.2	17.5	9.2	108	8.0	2	99
21 September	12.9	15.0	26.0	21.0	17.0	12.9	11.0	111	7.7	2	100
19 October	7.0	7.4	17.2	12.5	9.4	6.3	9.8	112	7.8	2	99
16 November	4.4	5.0	15.0	10.0	7.0	3.9	10.0	110	7.9	2	99

[a] Pump capacity = 200,000 GPM each.

Table 5.3. Comparison of the immediate effects of condenser passage and plume entrainment on phytoplankton carbon uptake, chlorophyll a concentration and total abundance seven hours after sample collection for all sampling locations, Kewaunee Nuclear Power Plant, January through November 1976.

Date	Location	Carbon Fixation Rate (mg C/m^3 per hr)	Sig. Diff. $P \leq 0.05$	Chlorophyll a Concentration (mg chl a/m^3)	Sig. Diff. $P \leq 0.05$	Total Phytoplankton Abundance (Units/ml)
27 January	E1	5.72		3.15		468
	E2	6.42	E2>E1	3.21	None	469
10 February	E1	11.28		3.21		648
	E2	11.89	None	3.15	None	1128
28 April	E0	17.69		6.93		3028
	E1	18.98	None	7.13	None	2982
	E2	19.52		6.93		2891
	E3	18.83		7.00		3135
	E4	19.28		6.93		3901
	E5	17.85		6.73		3108
25 May	E0	11.72	E4>E2,E1,E0,E5	3.00	E4>E2,E1	1229
	E1	10.90	E3>E2,E1,E0	2.61	E3>E2	906
	E2	10.45	E5>E2,E1	2.57		2031
	E3	14.79		3.27		1560
	E4	15.29		3.47		1343
	E5	13.27		2.93		1342
22 June	E0	7.73	E3>E2	2.55	All>E5	1121
	E1	7.26	All>E5	2.30		758
	E2	6.60		2.25		972
	E3	8.25		2.06		1444
	E4	6.92		1.88		1454
	E5	3.87		0.77		621
13 July	E0	5.32	None	1.13	E3>E5,E0,E2,E1	854
	E1	5.92		1.29	E4>E5,E0,E2	557
	E2	4.33		1.14	E1>E5	771
	E3	7.14		1.64		1150
	E4	5.85		1.42		928
	E5	4.24		0.92		481
24 August	E0	6.81	E1>E5,E4,E0,E2	1.84	E1>E5,E4,E0	975
	E1	10.58	E3>E5,E4,E0	3.25		1134
	E2	9.29	E2>E5,E4,E0	2.59		1274
	E3	10.15	E0>E5	2.28		1450
	E4	6.22		1.62		1015
	E5	5.10		1.58		754
21 September	E0	6.88		1.76		1263
	E1	9.57	None	2.35	E4>All	880
	E2	7.29		1.76		1175
	E3	12.50		3.33		1098
	E4	21.35		6.27		1975
	E5	8.44		1.97		1265
19 October	E0	9.96	E0>E5,E2,E1	3.67	E3>E5,E1,E2	1549
	E1	6.54	E3>E5,E2	1.83	E0>E5,E1	719
	E2	5.28		2.15		1318
	E3	8.96		4.00		1328
	E4	7.64		2.61		850
	E5	5.08		1.57		1264
16 November	E0	3.29	E2,E3,E4>E5	1.68	E0>E5,E4,E2	1480
	E1	3.30		1.64		919
	E2	3.81		1.54		1029
	E3	3.78		1.58		1450
	E4	3.70		1.54		1124
	E5	2.95		1.52		1084
Mean of All Months	E1	9.01		2.88		997
	E2	8.49		2.73		1306
Mean of April-November	E0	8.68		2.82		1437
	E1	9.13		2.80		1107
	E2	8.32		2.62		1433
	E3	10.55		3.14		1577
	E4	10.78		3.22		1574
	E5	7.60		2.25		1240

($P \leq 0.05$) differences between locations were recorded only during January and August for carbon fixation rates and were never observed for chlorophyll *a* concentrations between locations. Statistical analyses of 1976 entrainment data resulted in the same significant differences between forebay and discharge samples as recorded in 1975 (Redmond 1976). Annual mean (based on 10 months' data) carbon fixation rates and chlorophyll *a* concentrations of samples collected from the discharge canal (Location E-2) were approximately 6% lower than values measured for both parameters in samples collected from the forebay (Location E-1).

The productivity index (mg C/mg chl *a*-hr) calculated using annual mean carbon fixation rate and chlorophyll *a* concentration indicated that phytoplankton collected from forebay and discharge locations exhibited a similar degree of photosynthetic efficiency before and after condenser passage (Table 5.3).

Total phytoplankton abundance observed in samples from the discharge tunnel was approximately 30% higher (6 of 10 months) than abundance recorded for intake forebay samples (Table 5.3). Phytoplankton abundance data exhibited a somewhat higher degree of variability between locations from month to month than did either carbon fixation or chlorophyll *a* data.

The phytoplankton assemblage in the vicinity of KNPP was composed primarily of Bacillariophyta (diatoms) from Januar through May and August 1976 (Figure 5.1). The diatom population declined in June and July while the numbers of Chrysophyta and Cryptophyta increased during these months (Appendix 5A). Relatively large

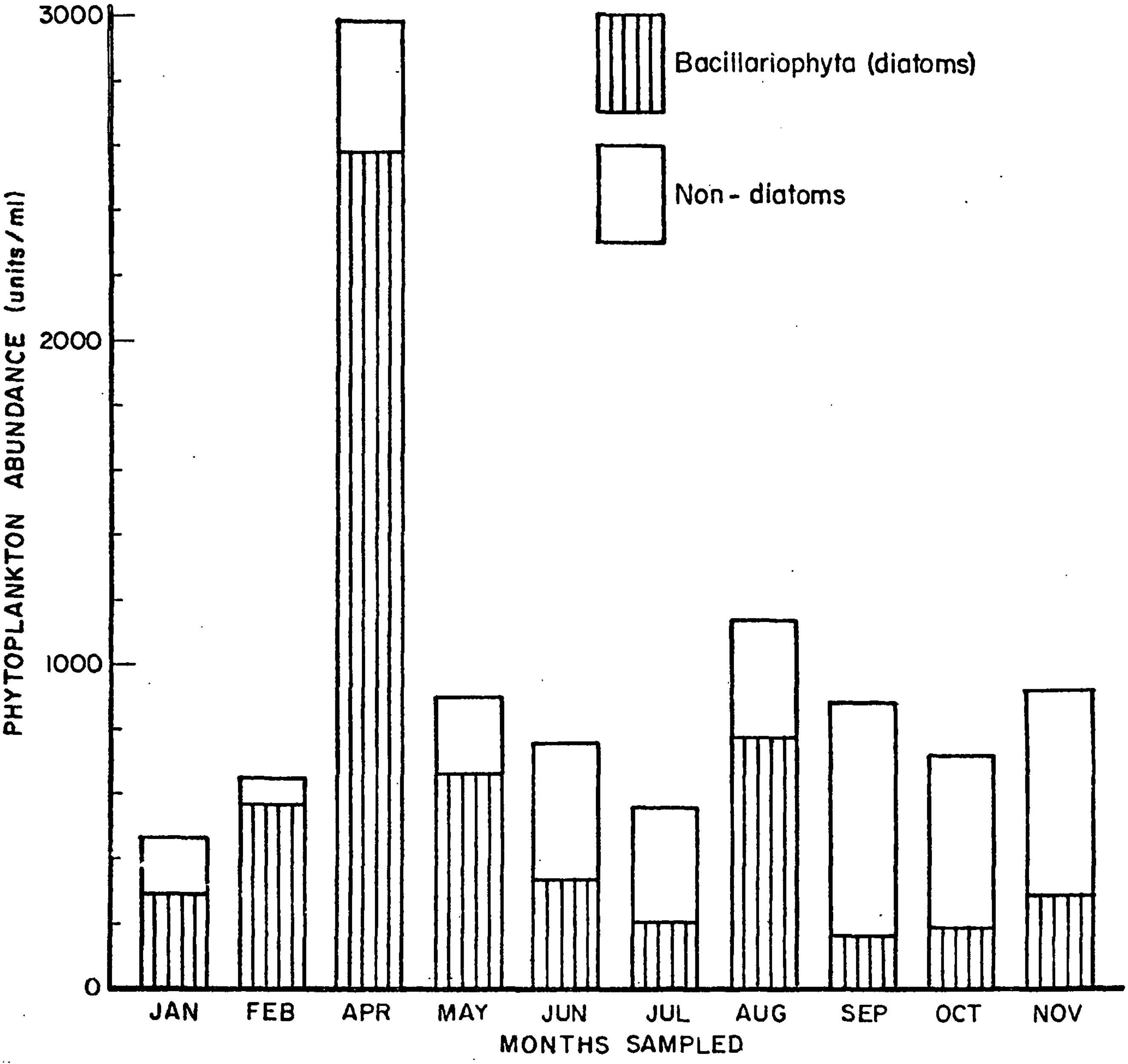

Figure 5.1. Abundance of total phytoplankton and principal phytoplankton divisions present at the intake, seven hours after sample collection, Kewaunee Nuclear Power Plant, January through November 1976.

increases in the abundance of nondiatoms, especially the Cyanophyta, were observed during the September through November sampling periods These increases in abundance of non-diatoms were generally not location specific and occurred throughout the entire study area. A similar Fall decline in the diatom population has been documented by Holland (1969) for northwestern Lake Michigan. Immediate effects of Plant entrainment appeared not to be species-selective since phytoplankton species composition remained generally similar at all locations throughout the sampling periods (Appendix 5A).

Effects of condenser passage on phytoplankton viability measured at the discharge relative to the intake forebay were apparently not correlated to discharge water temperatures or magnitude of the ΔT measured. Similar results were observed at Kewaunee during operational monitoring by Jones et al (1975) and Redmond (1976) and at the Zion Station by Redmond (1974). The ambient water temperature at the intake forebay did, however, appea to be correlated to the effect of plant entrainment on phytoplankto carbon fixation rates. Carbon uptake rates appeared accelerated as a result of condenser passage when the intake water temperature was at or below 6 C, whereas rates were depressed following plant passag when the intake water temperature was in excess of 7 C. Morgan and Stross (1969) also reported that stimulation or inhibition of carbo uptake rates following condenser passage was dependent on intake (o ambient) water temperature.

Immediate effects of condenser passage on phytoplankton carbon fixation rates, chlorophyll *a* concentrations, abundance and species composition observed during the 1976 entrainment study were generally minor with similar findings reported in the following entrainment studies: Point Beach, Wisconsin (Wisconsin Electric Power Company and Wisconsin - Michigan Power Company 1973); Zion, Illinois (Redmond 1974); and Kewaunee, Wisconsin (Jones et al 1975, Redmond 1976).

B. Delayed Effects (24 through 72 Hours after Sample Collection)

Phytoplankton samples collected at the discharge (Location E-2) exhibited chlorophyll *a* concentrations which averaged (annual mean) 7%, 10% and 10% lower than forebay samples at 24, 48 and 72 hours after sample collection, respectively (Tables 5.3, 5.4, 5.5). Chlorophyll *a* concentration increased steadily throughout the holding period with concentrations of forebay samples rising at a more rapid rate than those of discharge samples. Significant differences ($P \leq 0.05$) in chlorophyll *a* concentration between locations were only noted in 6 of 30 comparisons throughout the 72 hour sample holding period (Table 5.4, 5.5). These data indicate that delayed effects of entrainment on phytoplankton chlorophyll *a* concentration were negligible during 1976 sampling periods.

Annual mean phytoplankton carbon fixation rates measured in discharge samples from 24 through 72 hours exhibited a higher degree of inhibition than did 7 hour discharge samples (Table 5.4, 5.5). Mean reductions in discharge sample carbon fixation rates relative to intake rates were 24%, 12% and 17% at 24, 48 and

Table 5.4. Comparison of delayed effects of condenser passage and plume entrainment on phytoplankton carbon uptake and chlorophyll *a* concentrations 24 and 48 hours after sample collection, Kewaunee Nuclear Power Plant, January through November 1976.

		24 Hours After Collection				48 Hours After Collection			
Date	Location	Carbon Fixation Rate (mg C/m^3 per hr)	Sig. Diff. $P \leq 0.05$	Chlorophyll *a* Concentration (mg chl a/m^3)	Sig. Diff. $P \leq 0.05$	Carbon Fixation Rate (mg C/m^3 per hr)	Sig. Diff. $P \leq 0.05$	Chlorophyll *a* Concentration (mg chl a/m^3)	Sig. Diff. $P \leq 0.05$
27 January	E1	6.19	None	2.82	None	a		2.83	None
	E2	4.71		2.76				2.75	
10 February	E1	14.06	None	3.29	None	9.06	None	3.31	None
	E2	14.15		3.08		9.66		3.24	
28 April	E0	16.79	None	6.53	E2,E3,E4>E0	6.69	E3>E1	7.33	E4>E2
	E1	17.42		7.13		4.65		7.53	
	E2	16.86		7.47		5.25		7.00	
	E3	19.18		7.40		7.08		7.73	
	E4	17.66		7.27		5.44		8.13	
	E5	16.16		7.00		6.96		7.20	
25 May	E0	12.36	E4>E0	3.53	E3>E1,E0	10.66	None	3.13	E3>E5
	E1	12.64	All>E2	3.47	E4>E1,E0	13.74		3.47	
	E2	1.04		2.67	E5>E1,E0	14.96		2.93	
	E3	13.24		4.07	All>E2	12.96		3.87	
	E4	15.71		4.00		13.30		3.33	
	E5	13.84		3.93		12.51		2.67	
22 June	E0	10.09	E3>E2	2.79	All>E5	10.99	E3>E5,E2,E4	3.65	E0>E4
	E1	9.49	All>E5	2.60		11.48	E1>E5	3.39	All>E5
	E2	7.67		2.39		8.80	E0>E5	2.95	
	E3	10.98		2.59		13.58	E4>E5	3.36	
	E4	9.58		2.14		10.16		2.81	
	E5	5.02		0.99		6.25		1.35	
13 July	E0	5.39	E3>E2,E0,E5	1.12	E3>All	4.36	E1>E2,E0	1.19	E3>E2,E0,E4,E5
	E1	6.88	E4>E2,E0	1.37		6.58	E3>E2,E0	1.43	
	E2	4.41	E1>E2,E0	1.07		3.85	E5>E2,E0	1.16	
	E3	7.52	E5>E2	1.82		6.46		1.85	
	E4	6.96		1.41		5.08		1.33	
	E5	5.98		1.07		6.31		1.39	
24 August	E0	8.28	None	2.10	E1>E5,E4,E0,E3	6.82	E1>E0,E4,E5	1.60	E2>E4,E5,E0
	E1	13.08		2.93	E2>E5,E4,E0,E3	11.62	E3>E0,E4,E5	2.78	E1>E4,E5,E0
	E2	10.75		2.83	E3>E5,E4,E0	10.31	E2>E0,E4,E5	2.81	
	E3	10.78		2.49	E0>E5,E4	10.90		2.19	
	E4	11.22		1.68		6.96		1.48	
	E5	8.08		1.54		7.86		1.52	
21 September	E0	8.77	E3>E2,E5,E0	1.70	E3>E2,E0,E5,E1	6.34	E3>E2,E0,E5,E1	1.51	E3>E0,E2,E5,E1
	E1	10.63	E4>All	2.08	E4>All	9.01	E4>All	1.99	E4>All
	E2	7.54		1.65		5.54		1.52	
	E3	17.92		4.47		16.07		4.45	
	E4	26.98		5.27		26.18		6.60	
	E5	8.45		1.81		7.51		1.70	
19 October	E0	9.90	E3>E2,E5,E1,E4	2.28	E3>All	8.00	E3>E5,E2,E1	3.03	E3>E5,E2
	E1	5.72	E0>E2,E5,E1	1.74		5.18		2.35	E0>E5
	E2	5.20	E4>E2,E5,E1	1.52		3.81		2.08	
	E3	12.08		9.13		9.66		3.53	
	E4	8.16		1.57		7.02		2.84	
	E5	5.28		1.15		3.74		1.50	

Table 5.4. (continued)

		24 Hours After Collection				48 Hours After Collection			
Date	Location	Carbon Fixation Rate (mg C/m^3 per hr)	Sig. Diff. $P \leq 0.05$	Chlorophyll *a* Concentration (mg chl$^{\underline{a}}$/m^3)	Sig. Diff. $P \leq 0,05$	Carbon Fixation Rate (mg C/m^3 per hr)	Sig. Diff. $P \leq 0.05$	Chlorophyll *a* Concentration (mg chl$^{\underline{a}}$/m^3)	Sig. Diff. $P \leq 0.05$
16 November	E0	3.58	E5>E0,E2,E3	1.52	E3,E4,E1,E2>E0	4.09	E5>E0,E2,E1,E3	1.58	E5>E2,E0,E3,E1
	E1	4.16		1.67		4.44		1.67	E4>E2,E0
	E2	4.00		1.63		4.34	E4,E3>E0	1.54	E1>E2
	E3	4.13		1.69		4.54		1.64	
	E4	4.21		1.69		4.74		1.76	
	E5	4.94		1.60		5.10		1.80	
Mean of all Months	E1	10.03		2.91		8.42		3.08	
	E2	7.63		2.71		7.39		2.80	
Mean of April-November	E0	9.40		2.70		7.24		2.88	
	E1	10.00		2.87		8.34		3.08	
	E2	7.18		2.65		7.11		2.75	
	E3	11.98		4.21		10.16		3.58	
	E4	12.56		3.13		9.86		3.54	
	E5	8.47		2.39		7.03		2.39	

[a] Samples unusable,

Table 5.5. Comparison of delayed effects of condenser passage and plume entrainment on phytoplankton carbon uptake, chlorophyll a concentrations and total abundance 72 hours after sample collection for all sampling location Kewaunee Nuclear Power Plant, January through November 1976.

Date	Location	Carbon Fixation Rate (mg C/m^3 per hr)	Sig. Diff. $P \leq 0.05$	Chlorophyll a Concentration (mg chl a/m^3)	Sig. Diff. $P \leq 0.05$	Total Phytoplankton Abundance (Units/ml)
	E1	4.65		3.09		336
27 January	E2	2.58	None	2.67	E1>E2	485
	E1	13.48		4.93		2082
10 February	E2	12.09	None	4.93	None	2303
	E0	12.31		7.87		
28 April	E1	11.64	None	7.13	None	4241
	E2	10.61		7.33		3764
	E3	11.81		8.47		
	E4	12.06		8.13		
	E5	9.86		7.53		
	E0	10.12	None	3.07	E3>E0,E1,E5	
25 May	E1	11.88		3.33	E4>E0,E1	2261
	E2	10.28		2.73	E5>E0	1707
	E3	12.06		3.80	All>E2	
	E4	12.13		3.67		
	E5	11.08		3.40		
	E0	9.20	E3>E5,E4,E2,E0	3.37	E3>E4,E2,E1,E0	
22 June	E1	10.13	E0,E1>E5	3.23	E0>E4,E2	1206
	E2	7.88		2.88	E1>E4,E2	1447
	E3	12.22		3.51	All>E5	
	E4	7.84		2.75		
	E5	5.78		1.60		
	E0	3.38	E5>E2,E0,E4	0.95	E3>All	
13 July	E1	5.15	E3>E2,E0,E4	1.35	E5>E2,E0	861
	E2	2.87	E1>E2,E0	0.95	E4>E2,E0	1001
	E3	5.59		1.68	E1>E2,E0	
	E4	4.79		1.36		
	E5	5.70		1.46		
	E0	6.08	E1>E4,E0,E5,E3	1.66	E2>E4,E5,E0	
24 August	E1	12.33	E2>E4,E0,E5	2.77	E1>E4,E5,E0	2741
	E2	10.83	E3>E4,E0,E5	2.89	E3>E4,E5,E0	1843
	E3	9.37		2.38		
	E4	5.87		1.50		
	E5	6.28		1.64		
	E0	5.60	E4>E5,E1,E2,E0	1.83	E4>E2,E5,E0,E1	
21 September	E1	5.42	E3>E5	2.07		2315
	E2	5.43		1.67		1759
	E3	9.97		3.85		
	E4	14.07		5.87		
	E5	1.63		1.69		
	E0	7.75	E3>E2,E5,E1	4.33	E0>E5,E2	
19 October	E1	4.38	E0>E2,E5,E1	2.93	E3>E5,E2	2071
	E2	3.41	E4>E2,E5	2.00		1390
	E3	9.01		3.80		
	E4	7.18		2.87		
	E5	3.50		1.93		
	E0	3.31	None	1.77	E5>E2,E3	
16 November	E1	4.54		1.86		1343
	E2	3.38		1.68		1845
	E3	3.78		1.70		
	E4	4.34		1.93		
	E5	4.16		2.00		
Mean of	E1	8.36		3.27		1946
all Months	E2	6.94		2.97		1754
Mean of	E0	7.22		3.11		
April-November	E1	8.18		3.08		
	E2	6.84		2.77		
	E3	9.23		3.65		
	E4	8.54		3.51		
	E5	6.00		2.66		

72 hours after sample collection, respectively. During all sampling months, differences between intake and discharge carbon uptake rates were significant ($P \leq 0.05$) during the 24 through 72 hour holding period in only 4 of 30 comparisons. Although a general decline in carbon fixation rates was observed for both intake and discharge samples from 7 through 72 hours, the rate of decline of discharge samples was greater than the rate of decline of intake samples. The difference in carbon fixation rate decline noted between intake and discharge samples may be indicative of delayed inhibition of photosynthesis between 24 and 72 hours after sample collection.

Phytoplankton abundances measured at both forebay and discharge locations after 72 hours were higher than abundances measured at 7 hours after sample collection (Tables 5.3 and 5.5). The magnitude of increase was again higher for intake samples (95%) than for discharge samples (34%), indicating a possible after effect of condenser passage. Species composition between locations remained relatively stable over the 72 hour holding period (Appendix 5A).

2. Plume Entrainment

Effects of thermal plume entrainment on phytoplankton viability were assessed by comparisons of Locations E-3 and E-4 with the control Location E-5 (Table 5.1). It should be noted before any comparisons are made that Location E-0 exerted some influence on Locations E-3 and E-4. Because water sampled at Locations E-3 and E-4 may have contained varying amounts of water from Location E-0, values for carbon fixation rates, chlorophyll a concentrations and phytoplankton abundance were usually lower at Location E-5 than at Location E-0 throughout the year. Differences observed in these parameters between Locations E-3 and E-4 relative to Location E-5, therefore, may result in part from differences in phytoplankton densities rather than resulting entirely from thermal plume entrainment.

a. Immediate Effects (Seven Hours after Sample Collection)

Location E-3: Phytoplankton samples collected in this part of the thermal plume (50% of ΔT) exhibited mean carbon fixation rates which were approximately 39% higher than carbon uptak rates measured for phytoplankton sampled at Location E-5 (Table 5.3) These increases in productivity were statistically significant ($P \leq 0.05$) in 4 of the 8 months sampled. Mean phytoplankton chlorophyll a concentrations displayed a similar trend with values measured 7 hrs after sample collection at Location E-3 being approximately 40% higher than at Location E-5 (Table 5.3). These increases were significant ($P \leq 0.05$) in 3 of 8 months sampled. Photosynthetic efficiencies calculated for samples from both locations E-3 and E-5 were virtually equal, however, with values of 3.36 and 3.38 mg C/mg chl a-hr, respectively. Higher phytoplankton abundance (27%) was also observed at Location E-3 relative to Location E-5 and could be at least partially responsible for the increases noted in carbon fixation rates and chlorophyll a concentrations at Location E-3. Although occasional monthly differences in species composition were observed between Location E-3 and E-5, no consistent pattern was evident. The differences apparently were due to natural spatial variability of the phytoplankton community near the plant (Appendix 5A). The increased productivity noted in this portion of the thermal plume was similar to results documented at Kewaunee in 1975 (Redmond 1976). Edsall and Yocum (1972) documented comparable results and suggested these increases may be due to introduction of the phytoplankton into warmer, well-lighted and nutrient-rich inshore surface waters.

Location E-4: Phytoplankton sampled from this portion of the thermal plume (20% ΔT) displayed almost indentical physiological responses as observed for phytoplankton sampled from the warmer plume water at Location E-3. At Location E-4, carbon fixation rates, chlorophyll a concentrations and phytoplankton abundance were 42%, 43% and 27% higher, respectively, than values for the same parameters measured at Location E-5 at 7 hours after sample collection (Table 5.3). Increases in carbon fixation rates and chlorophyll a concentrations were each significant ($P \leq 0.05$) at Location E-4 relative to Location E-5 in 3 of 8 months. Again, the photosynthetic efficiency of phytoplankton collected from Location E-4 (3.35 mg C/mg chl a-hr) was nearly identical to the efficiency of phytoplankton from the control Location E-5 (3.38 mg C/mg chl a-hr).

b. Delayed Effects (24 through 72 hours after Sample Collection)

Location E-3: Phytoplankton samples were analyzed at 24, 48 and 72 hours after sample collection in an attempt to study delayed effects of plume entrainment on phytoplankton carbon uptake rates and chlorophyll a concentrations. Carbon fixation rates decreased from 7 through 72 hours, but relative differences in that parameter between Locations E-3 and E-5 increased to 54% by the end of the sample holding period indicating a possible delayed effect of plume entrainment. Chlorophyll a concentrations measured in samples from Location E-3 were 76%, 50% and 37% higher after 24, 48 and 72 hours, respectively, than in samples from the control location and exhibited no evidence of recovery from the immediate effects of plume entrainment measured 7 hours after sample collection. Productivity indices (mg C/mg chl a-hr) calculated at each time omterval indicated that the photosynthetic efficiency of phytoplankton in samples from Locations E-3 and E-5 were roughly equivalent throug out the sample holding period.

Location E-4: Throughout the 72 hour sample holding period, chlorophyll a concentrations were relatively stable at both Locations E-4 and E-5, while carbon uptake rates decreased. Phytoplankton samples from Location E-4 had carbon fixation rates and chlorophyll a concentrations which remained higher from 24 through 72 hours than samples collected at Location E-5 (Tables 5.4 and 5.5). Results observed during this time period were very similar to results observed at 7 hours after sample collection, indicating a lack of additional effects of, or recovery from entrainment in the thermal plume at KNPP.

IV. Summary and Conclusions

Immediate and delayed effects of plant and thermal plume entrainment were assessed at KNPP during 1976 on phytoplankton carbon fixation rates, chlorophyll a concentrations, abundance and species composition. Data analysis revealed the following:

1. The immediate impact of condenser passage on phytoplankton carbon fixation rates and chlorophyll a concentrations was considered minimal during 1976. Values for both parameters measured at the discharge were 6% (annual mean) lower than at the intake.

2. Phytoplankton abundance observed at the discharge was approximately 30% higher than at the intake at 7 hours after sample collection with no trends in species composition changes observed between the two locations.

3. Delayed effects of Plant entrainment were not evident for phytoplankton chlorophyll a concentrations and species composition during 1976 sampling periods. Carbon fixation rates and phytoplankton abundance measured from 24 through 72 hours after sample collection, however, exhibited some evidence of delayed reaction to Plant entrainment.

4. Phytoplankton subjected to thermal plume entrainment responded with increased carbon fixation rates, chlorophyll a concentrations and abundance relative to a Lake Michigan control location outside the influence of the thermal plume. Analyses conducted at 24, 48 and 72 hours after sample collection revealed no evidence of recovery toward ambient values for the three parameters mentioned.

5. The overall impact of KNPP on the physiology of the phytoplankton community near the Plant was an immediate general increase in productivity in the area of the thermal plume with some evidence of delayed reaction to entrainment between 24 and 72 hours after sample collection.

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NALCO ENVIRONMENTAL SCIENCES

Chapter 6

ZOOPLANKTON ENTRAINMENT

Anthony L. Restaino and William S. Iverson

OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR
KEWAUNEE NUCLEAR POWER PLANT

SIXTH ANNUAL REPORT
January - December 1976

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Chapter 6

ZOOPLANKTON ENTRAINMENT

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I. Introduction

Kewaunee Nuclear Power Plant (KNPP) is an electrical generating facility which utilizes Lake Michigan water in a once-through or open cycle cooling system. Coincidental with this cooling process, large numbers of zooplankton are involuntarily entrained and passed through the system. The purpose of this study is to evaluate what effects such Plant passage has on these organisms. The immediate and long-term effects of condenser passage and plume entrainment on the zooplankton community were documented when a measurable ΔT was present at the point of discharge. The study was a continuation of the 1973 preoperational monitoring program (Wetzel and Restaino 1974) and 1974-1975 operational environmental monitoring program (Wetzel 1975 and Wetzel et al 1976).

The specific objectives of this study were:

1. to document zooplankton species composition and abundance in the Plant and thermal plume;
2. to assess the immediate and delayed effects of Plant entrainment on zooplankton; and
3. to determine the immediate and delayed effects of plume entrainment on zooplankton in the lake.

II. Field and Analytical Procedures

Zooplankton entrainment samples were collected monthly at KNPP during January and February and from April through November 1976. Samples were not collected during March due to Plant shutdown. Duplicate intake and discharge samples were taken throughout the study period. Additional duplicate lake samples were collected at Locations E-0, E-3, E-4 and E-5 from April through November (Table 6.1). All samples were taken within one meter below the surface except for Location E-0 where samples were collected near the intake structure orifice (16 ft depth). Samples used for determining the entrained zooplankton abundance and species composition were obtained from Location E-2 (discharge).

Zooplankton entrainment samples were collected utilizing a filter-pump system similar to that described by Icanberry (1972). A #10 mesh net insert (153 μ aperture) was used within the system to collect the microcrustacean zooplankton. Rotifers were too small, lacking sufficient morphological development to visually differentiate live from dead. The volume of water filtered was measured using a calibrated in-line water meter. Each sample was concentrated to a 200 ml volume and maintained at ambient lake temperature. Subsamples of 4.0-80.0 ml were drawn with an automatic pipette from each concentrated sample and placed into a partitioned Petri dish. Live and dead zooplankton were separated under a stereozoom microscope within 20 minutes and at four hours after sample collection.

Table 6.1. Description of sampling locations for entrainment studies near the Kewaunee Nuclear Power Plant during 1976.

Sampling Location	Description
E-0	Intake location, 1600 feet offshore near the openings of the intake structure.
E-1	Intake location, in Plant forebay.
E-2	Discharge location, prior to mixing with Lake Michigan.
E-3	Plume location, where the temperature is at the forebay temperature plus 50% of the ΔT.
E-4	Plume location, where the temperature is at the forebay temperature plus 20% of the ΔT.
E-5	Control location, outside the plume (north or south of the plume depending on plume configuration).

Zooplankton observed during the first (20 min) period were recorded as motile and immotile rather than live and dead to account for possible recovery from temporary shock following condenser passage. Immotility is defined as the absence of appendicular and visceral movements upon probing. The term mortality denotes those organisms which failed to recover (become motile) four hours after sample collection. The percent of immotile or dead zooplankton at each location was calculated using the following formula:

$$\frac{\text{number of immotile or dead zooplankton/sample}}{\text{Total zooplankton/sample}} \times 100 = \begin{array}{c}\text{percent}\\ \text{immotility}\\ \text{or}\\ \text{mortality}\end{array}$$

The percent differential immotility or mortality of zooplankton due to condenser passage was determined by the following formula:

$$\begin{array}{l}\text{\% discharge}\\ \text{immotility}\\ \text{or mortality}\end{array} - \begin{array}{l}\text{\% intake}\\ \text{immotility}\\ \text{or mortality}\end{array} = \begin{array}{l}\text{\% differential immotility}\\ \text{or mortality due to}\\ \text{entrainment}\end{array}$$

Zooplankton were preserved in 3% formalin at the conclusion of each survival analysis for later determination of population densities and species composition. Population densities (No./m^3) for each replicate were calculated using the following; organisms separated during the 0 and 4 hour survival analyses, subsample volum recorded during those observations, sample volume (200 ml) and total volume of water pumped. Zooplankton were identifical to the lowest positive taxon, using keys by Brooks (1957, 1959), Wilson and Yeatman (1959), Gannon (1970) and Smirnov (1974).

To assess possible mechanical effects of condenser passage, the five to nine most abundant species from the survival analyses were ranked according to size based upon measurements documented by Gannon (personal communication from Dr. J.E. Gannon, University of Michigan Biological Station, Pellston, Michigan, letter dated 13 October 1971), Wells (1970) and Brooks (1959), with which the relationships between size and immotility were determined.

Statistical analysis applied to zooplankton entrainment data were: (1) one-way analysis of variance showing significant differences ($P \leq 0.05$) between abundances of zooplankton among sampling locations; (2) Chi-square analysis, comparing zooplankton immotility and/or mortality differences among locations; and (3) linear weighted regression on proportions comparing zooplankton immotility against species size for the intake and discharge locations (Feiss 1973).

III. Results and Discussion

A. Plant Operating Data

KNPP was operating between 75% and 100% (390-520 MWe) power capacity, during 1976 sampling periods (Table 6.2). During eight of the ten sampling dates the amount of power generated exceeded 98% (510 MWe). Cooling water flow rates ranged from 200,000 GPM (one circulating pump) in January and February to 400,000 GPM (two circulating pumps) from April through November. The temperature rise across the condensers (ΔT) ranged from 7.5 C to 16.0 C with the highest ΔT occurring in February. Lake Michigan water temperatures taken from Locations E-5 and/or Location E-1 ranged from 0.0 C in January to 12.5 C in July. Forebay and lake water temperatures were the same for all months except for June when temperatures were stratified and from August through November when plume water may have been recirculated to the forebay.

B. Species Composition and Abundance

Seventeen copepod and eleven cladoceran species comprised the 28 taxa entrained by KNPP's cooling water system and identified from the Plant's discharge waters during January, February and from April through November 1976. Total zooplankton (microcrustacea) density ranged from $160/m^3$ in May to $70379/m^3$ in September and averaged $13635/m^3$ during 1976 (Table 6.3). Zooplankton numbers were relatively low during January, February and from April through June, averaging $1757/m^3$. Densities increased sharply in July ($24635/m^3$) and averaged $25513/m^3$ from July through November.

Immature copepod and cladoceran densities fluctuated throughout the study period (Figure 6.1). However, they appeared to increase during late spring and early summer with a gradual but erradic decline throughout the later part of the year. Immatures were most predominant during March and June, averaging 856/m^3 and comprising 76% and 84% of the total zooplankton population, respectively (Table 6.3). Copepod densities were most commonly represented by immature nauplii and calanoid and cyclopoid copepodites throughout the study period. Nauplii, calanoid copepodites and cyclopoid copepodites had individual population densities averaging 400/m^3, 585/m^3 and 1777/m^3, respectively, and comprised nearly 20% of the total zooplankton population. Daphnia spp. (immature) was the only immature cladoceran observed during the study period. Daphnia spp. (immature) averaged 149/m^3 during six of ten months sampled with peak density (567/m^3) occurring in July.

Adult copepods (709/m^3) comprised 96% of the total zooplankton population in April, when immature and adult cladoceran densities were extremely low, 19/m^3 and 11/m^3, respectively (Table 6.3). During late spring, summer and fall, adult copepod densities were low and relatively constant, averaging 7.6% of the total zooplankton assemblage. Adult copepods were represented primarily by Cyclops bicuspidatus thomasi, Diaptomus oregonensis, D. ashlandi and D. minutus. Cyclops bicuspidatus thomasi was identified throughout the period, as in previous studies (Wetzel 1975 and Wetzel et al 1976), averaging 240/m^3 and comprising approximaximately 2% of the total zooplankton population. Diaptomus oregonensis

Table 6.2. Summary of physical parameters recorded during zooplankton entrainment sampling at Kewaunee Nuclear Power Plant during January, February, and from April through November 1976.

Month	Ambient Lake Control (E5)	Intake Pipe (E0)	Intake (Forebay) (E1)	Discharge (E2)	Plume (E3)	Plume (E4)	ΔT E2-E1 (°C)	Percent Power and MWe Output	Number of Circulating Water Pumps	Intake Flow (GPM)
26 January	-[a]	-	0.0	12.2	-	-	12.2	99 (515 MWe)	1	200,000[b]
9 February	-	-	1.0	17.0	-	-	16.0	99 (515 MWe)	1	200,000
27 April	-	5.5	5.5	13.0	13.0	-	7.5	75 (390 MWe)	2	400,00
24 May	10.5	10.5	10.5	19.5	15.0	12.0	9.0	90 (468 MWe)	2	400,000
21 June	8.8	7.8	8.0	18.5	13.5	10.5	10.5	99 (515 MWe)	2	400,000
12 July	12.5	12.5	12.5	23.0	17.8	14.6	10.5	100 (520 MWe)	2	400,000
23 August	9.5	9.5	10.5	19.5	15.0	12.5	9.0	99 (519 MWe)	2	400,000
20 September	11.9	12.1	12.0	21.5	17.0	14.0	9.5	99 (519 MWe)	2	400,000
18 October	6.2	7.2	7.1	17.1	12.1	9.1	10.0	99 (519 MWe)	2	400,000
15 November	3.6	4.3	3.9	13.0	8.5	5.7	9.1	99 (519 MWe)	2	400,000

[a] Samples not collected.
[b] Pump capacity = 200,000 GPM each.

Table 6.3. Zooplankton species (Microcrustacea) abundances (No./m^3) from Location E2 at Kewaunee Nuclear Power Plant during January, February, and from April through November 1976.

Organisms	Sampling Dates									
	1-26	2-9	4-27	5-24	6-21	7-12	8-23	9-20	10-18	11-15
Total Zooplankton	2937	3049	739	160	1900	24635	10519	70379	13182	8849
Total Copepoda	2932	3049	727	145	1835	7389	6646	9222	5305	3877
nauplii	48	24	6	80	564	283	831	1894	239	34
calanoid copepodites	79	66	1	18	284	2288	698	897	798	725
cyclopoid copepodites	1334	1513	11	24	737	3745	3821	3788	2512	286
Cyclops bicuspidatus thomasi	136	80	87	4	97	608	781	249	290	67
Cyclops vernalis	0	14	1	0	7	61	83	1097	867	0
Diaptomus ashlandi	386	362	67	8	33	40	150	100	10	0
Diaptomus minutus	44	43	122	6	33	202	33	0	0	47
Diaptomus oregonensis	702	400	415	2	80	0	66	0	60	273
Diaptomus sicilis	31	5	1	0	0	0	0	0	0	0
Epischura lacustris	5	0	0	0	0	0	0	0	20	2299
Eucyclops agilis	0	0	1	0	0	0	0	0	0	0
Eucyclops prionophorus	0	10	0	0	0	0	0	0	0	0
Eurytemora affinis	0	0	0	1*	0	61	17	349	10	53
Limnocalanus macrurus	101	137	2	0	0	0	0	0	0	0
Mesocyclops edax	0	0	0	0	0	0	0	0	60	0
Tropocyclops prasinus	0	0	3	2	0	101	166	848	439	93
Harpacticoida	66	395	10	1	0	0	0	0	0	0
Total Cladocera	5	0	12	14	65	17246	3873	61157	7877	4972
Alona spp.	0	0	1	0	7	162	17	349	10	0
Bosmina longirostris	0	0	10	14	50	15911	3689	59610	7497	4007
Ceriodaphnia spp.	0	0	0	0	0	0	0	50	0	0
Chydorus sphaericus	0	0	0	1*	4	425	150	798	70	0
Daphnia galeata mendotae	0	0	0	0	0	20	0	0	70	472
Daphnia pulecaria	5	0	0	0	0	0	0	0	0	0
Daphnia retrocurva	0	0	0	0	0	101	17	200	0	319
Daphnia spp. (immature)	0	0	1	0	4	567	0	100	60	80
Eubosmina coregoni	0	0	0	0	0	40	0	50	170	80
Eurycercus lamellatus	0	0	0	0	0	20	0	0	0	0
Holopedium gibberum	0	0	0	0	0	0	0	0	0	14

* Less than one per cubic meter.

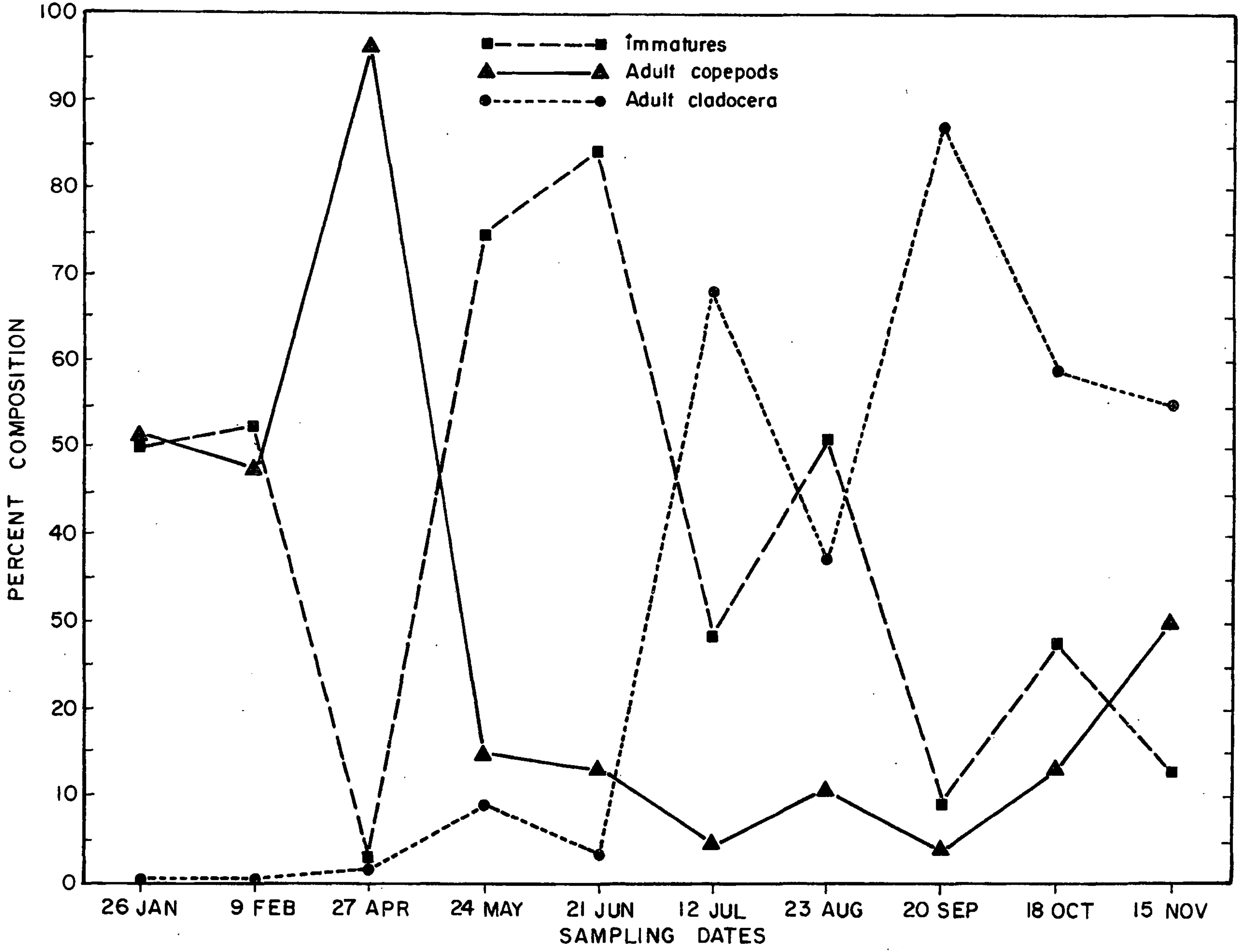

Figure 6.1. Percent species composition of the three major groups of microcrustacea zooplankton entrained at Kewaunee Nuclear Power Plant during January, February, and from April through November 1976.

(508/m^3), *D. ashlandi* (272/m^3) and *D. minutus* (70/m^3) accounted for 38% of the total copepod assemblage during the winter and early spring (January through April). *Diaptomus oregonensis* was the most abundant zooplankton species in April (415/m^3), comprising 56.2% of the total zooplankton assemblage.

Adult cladocera were most abundant during late summer and fall (July through November), comprising 74% of the total zooplankton population (Table 6.3). Increasing zooplankton density paralleled the late summer and fall emergence of several cladocera species. *Bosmina longirostris* (18143/m), *Chydorus sphaericus* (289/m^3), *Daphnia retrocurva* (127/m^3) and *Alona* spp. (108/m^3) were the most abundant cladocera from July through November. In September, when zooplankton density was highest, *B. longirostris* (61157/m^3) comprised 87% of the total population. Previous studies (Wetzel 1975 and Wetzel et al 1976) showed that annual peak population densities (September and October) near the Plant's discharge were influenced by seasonal increases in *B. longirostris*.

Total zooplankton were significantly ($P \leq 0.5$) more abundant at Locations E-0, E-1 or E-2 during July, August and October than at the surface of the plume (Locations E-3 and E-4) or Location E-5 (lake surface control) (Table 6.4). These differences were due to variations in density between surface and lake bottom (5-6 meters). Density differences among locations were not significant during April, June, September and November.

Immature copepods (calanoid and cyclopoid copepodites), during the summer months, were significantly more abundant at the

Table 6.4. Summary of one-way ANOVA with Tukey's multiple comparison of zooplankton abundances among locations at Kewaunee Nuclear Power Plant during January, February and from April through November 1976.

Organisms	27 Apr	24 May	21 Jun	12 Jul	23 Aug	20 Sep	18 Oct	15 Nov
Copepoda								
nauplii	-[a]	E1,E5>E4,E3 E0>E4	N.S.[b]	N.S.	N.S.	N.S.	E5,E0>E2	-
calanoid copepodites	-	N.S.	E1,E2,E4,E0,E3>E5 E1>E3	N.S.	N.S.	E5>E0,E2	N.S.	N.S.
cyclopoid copepodites	-	N.S.	E1,E0,E2,E3>E5	E2,E1,E3>E5,E0	E2,E1,E3,E4>E5,E0	N.S.	E0>E1,E2	N.S.
Cyclops bicuspidatus thomasi	E0,E1,E2>E3	- -	N.S.	E2>E4	E3>E5	N.S.	N.S.	N.S.
Diaptomus ashlandi	E0>E3	-	-	-	-	-	-	-
Diaptomus minutus	N.S.	-	-	-	-	-	-	-
Diaptomus oregonensis	N.S.	-	-	-	-	-	-	-
Epischura lacustris	-	-	-	-	-	-	-	E2,E1,E0>E5,E4,E3
Cladocera								
Bosmina longirostris	-	E1>E2	-	E2,E1>E4,E3,E5 E0>E4	E1>E5,E0	N.S.	E0>E5,E1	-
Total Zooplankton	N.S.	E1,E5>E3,E4,E2 E0>E3	N.S.	E2,E1>E4,E5	E1,E2,E3>E5,E0	N.S.	E0>E1,E5,E2,E3,E4	N.S.

[a] Insufficient number of organisms.
[b] No significant differences among locations.

intake, discharge and plume (Location E-3) than those observed at the lake surface control (Location E-5). When density differences were significant between Locations E-0 and E-3, abundant adult copepods such as C. bicuspidatus thomasi, D. ashlandi and Epischura lacustris were found to prefer depths below one meter from the surface. Bosmina longirostris, the predominant cladocera, was significantly more numerous within the forebay than at the lake surface control location during July and August. Density differences between locations were not significant for B. longirostris in September, although abundances observed during October were significantly greater near the intake pipe when compared to the forebay and lake surface control.

C. Plant Entrainment

The combined effects of thermal and mechanical factors during condenser passage on zooplankton were significant (P _ 0.05) throughout the study (Table 6.5). Total microcrustacea zooplankton immotility incurred during entrainment ranged from 1.4% to 14.4% and averaged 8.9% (Table 6.6). Zooplankton mortality decreased slightly four hours after collection, averaging 8.8%. Recovery of some immotile zooplankton from initial shock after condenser passage occurred on five of ten sampling dates. Previous studies at KNPP reported entrained zooplankton immotility and mortality ranging from 1.9% to 18.0% (Wetzel 1975 and Wetzel et al 1976).

Nauplii averaged 7.5% immotility and 9.0% mortality from May through August during periods of highest population density (Figure 6.2). During those months calanoid copepodites averaged

Table 6.5. Chi-square analysis of live-dead ratio between locations at 0 and 4 hours after sample collection at Kewaunee Nuclear Power Plant during January, February, and from April through November 1976.

Location	Months Sampled									
Comparisons	Jan	Feb	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
0 hrs										
E1 vs E2	E2>E1	E2>E1	E2>E1	E2>E1	E2>E1	E2>E1	E2>E1	E2>E1	-	E2>E1
E2 vs E3	x	x	-	-	E2>E3	-	-	-	-	E2>E3
E3 vs E4	x	x	x	-	-	-	E3>E4	-	E3>E4	-
E4 vs E5	x	x	x	-	-	-	E4>E5	-	-	-
4 hrs										
E1 vs E2	E2>E1	E2>E1	-	E2>E1	E2>E1	E2>E1	E2>E1	E2>E1	E2>E1	E2>E1
E2 vs E3	x	x	E3>E2	-	E2>E3	E2>E3	-	-	-	-
E3 vs E4	x	x	x	-	-	-	-	-	E3>E4	-
E4 vs E5	x	x	x	E4>E5	-	E4>E5	-	E4>E5	-	-

- Not significant at the 0.05 level.
x Samples not collected.

Table 6.6. Zooplankton immotility (0 hrs) and mortality (4 hrs) among locations at Kewaunee Nuclear Power Plant during January, February, and from April through November 1976.

		Percent Immotility and Mortality						
		Plant Locations			Lake Locations			
Total Zooplankton	Hours Analyzed	E1 (Intake)	E2 (Discharge)	Differential (E2 minus E1)	Control E0	Plume E3	Plume E4	Control E5
26 January	0 Immotility	2.2	15.3	13.2				
	4 Mortality	2.0	15.1	13.1	-[a]	-	-	-
9 February	0 Immotility	2.4	10.6	8.2				
	4 Mortality	3.0	20.2	17.2	-	-	-	-
27 April	0 Immotility	2.7	10.4	7.7	9.4	11.5		
	4 Mortality	5.4	8.8	3.4	7.3	28.3	-	-
24 May	0 Immotility	0.4	11.5	11.1	2.3	12.1	8.8	3.8
	4 Mortality	4.7	11.3	6.5	4.6	10.1	9.9	3.6
21 June	0 Immotility	2.4	16.8	14.4	8.8	8.8	6.4	2.8
	4 Mortality	6.2	24.3	18.1	6.5	15.5	10.8	6.2
12 July	0 Immotility	5.2	10.3	5.1	6.1	8.6	12.0	6.4
	4 Mortality	5.4	15.2	9.8	9.2	10.7	9.8	5.6
23 August	0 Immotility	3.6	11.3	7.7	7.1	15.0	8.3	5.3
	4 Mortality	2.7	10.8	8.1	7.0	15.1	9.7	8.5
20 September	0 Immotility	1.3	13.7	12.5	3.6	8.3	7.9	4.4
	4 Mortality	2.0	8.2	6.1	3.7	8.5	11.3	3.7
18 October	0 Immotility	4.9	6.3	1.4	1.3	4.7	2.5	2.5
	4 Mortality	1.7	3.9	2.2	2.7	5.7	3.3	2.6
15 November	0 Immotility	3.0	10.4	7.4	3.4	5.8	5.7	4.9
	4 Mortality	4.7	8.1	3.4	6.4	8.4	8.5	7.3
Mean	0 Immotility	2.8	11.7	8.9	5.2	9.4	7.4	4.3
	4 Mortality	3.8	12.6	8.8	5.9	12.8	9.0	5.4

[a] - Samples not collected

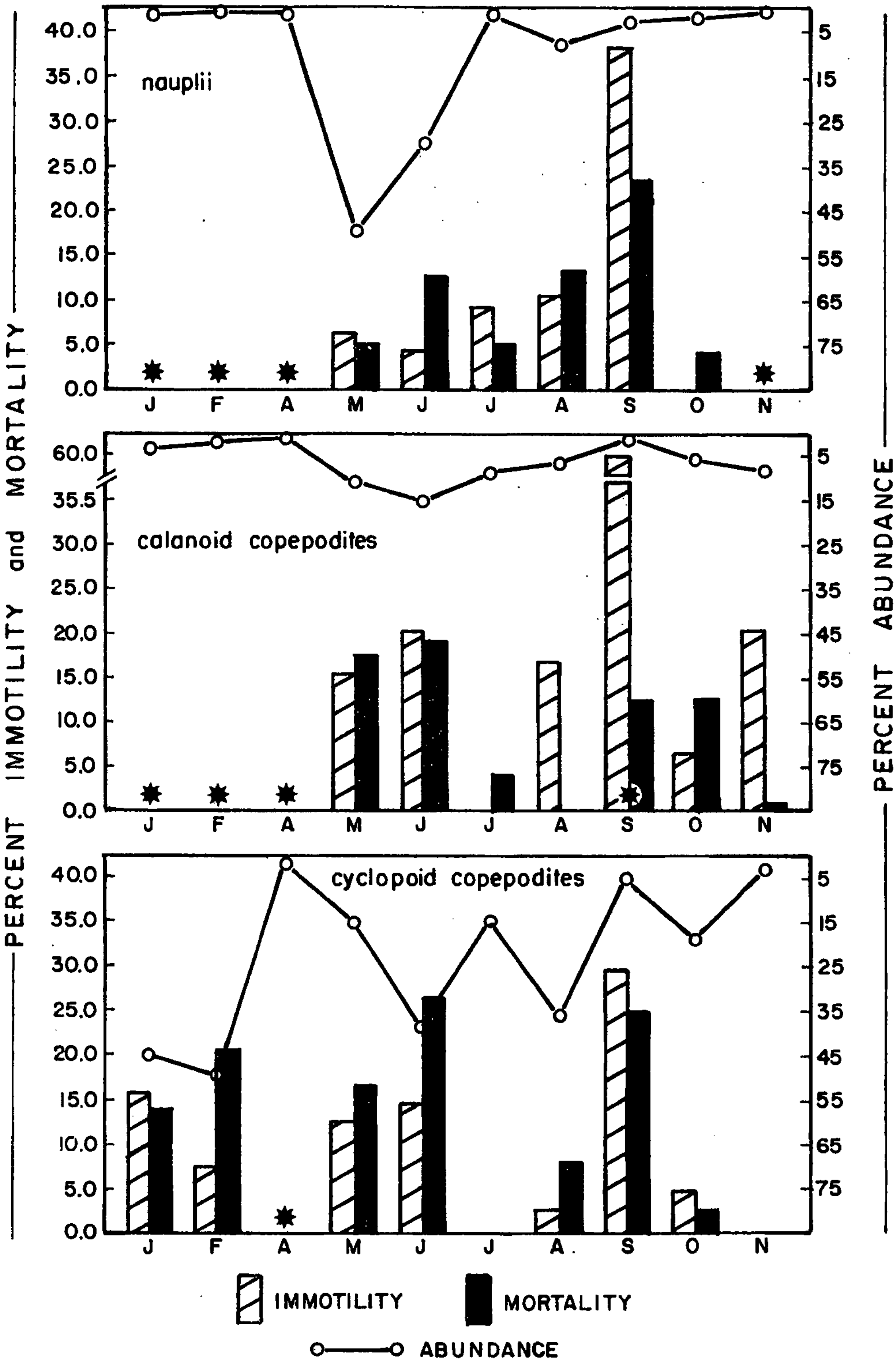

Figure 6.2. Effects from condenser passage on immature zooplankton at Kewaunee Nuclear Power Plant during January, February, and from April through November 1976. (Immotility and mortality-ascending scale; abundance-descending scale). Asterisk (*) denotes insufficient numbers of organisms.

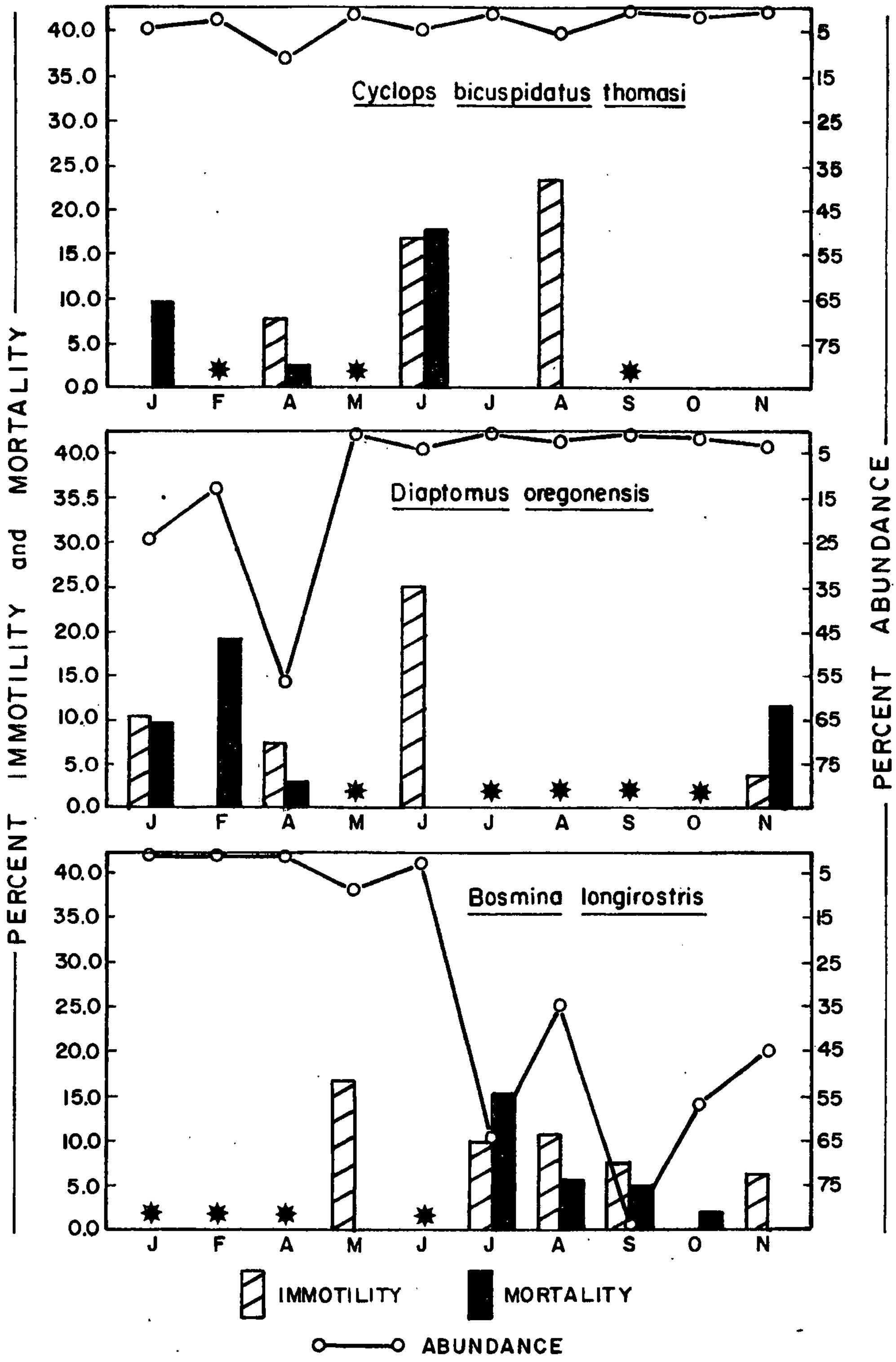

Figure 6.3. Effects from condenser passage on abundant adult zooplankton at Kewaunee Nuclear Power Plant during January, February, and from April through November 1976. (Immotility and mortality-ascending scale; abundance-descending scale). Asterisk (*) denotes insufficient numbers of organisms.

13.1% immotility and 10.2% mortality whereas immotility and mortality for cyclopoid copepodites averaged 7.5% and 12.9%, respectively. Calanoid copepodites were more susceptible to thermal effects durin entrainment than were nauplii and cyclopoid copepodites. Immature copepods (nauplii and calanoid and cyclopoid copepodites) were most susceptible to condenser passage in September, averaging 42.5% immotility, when the population constituted only 9% of the zooplankton assemblage. Condenser mortality in September averaged 20.4% with recovery of immotile organisms after condenser passage occurring for each immature form.

Entrainment effects for adult zooplankton were similar to those of immatures. Bosmina longirostris, a prevalent cladoceran comprising 35% to 85% of the zooplankton assemblage from July through November, averaged 6.8% immotility and 5.6% mortality (Figure 6.3). Highest immotility (9.8% and 10.8%) for B. longirostris occurred during July and August when discharge water temperatures were 23.0 C and 19.5 C, respectively. Immotility was low in October (0.0%) and November (6.2%) when discharge temperatures averaged 15.0 C. While comprising more than 14% of the zooplankton community, D. oregonensis and C. bicuspidatus thomasi averaged 9.4% and 6.8% immotility, respectively, with a mean mortality of 8.8% and 4.2% (Figure 6.3). Diaptomus ashlandi averaged 56% of the total zooplankton community in April, when immotility and mortality was less than 7%. Highest immotility for C. bicuspidatus thomasi occurred in July (16.7%) and August (23.1%) when the organism comprised 6% of the zooplankton assemblage.

There appeared to be no direct correlation between higher discharge water temperature and zooplankton immotility. Highest zooplankton immotilities occurred in January (13.2%) and June (14.4%) when discharge water temperatures were below 18.6 C (Table 6.6). When the discharge water temperature reached a maximum of 23.0 C in July, zooplankton immotility was 5.1%. Similar observations were reported in previous KNPP entrainment studies (Wetzel et al 1976). The effects of discharge water temperature of the magnitude experienced at KNPP were apparently not detrimental. Discharge water temperatures did not exceed upper lethal temperatures for entrained zooplankton. Studies by several workers have shown that condenser water temperatures below a critical level of 37.0 C during the summer do not cause substantial mortality (Churchill and Wojtalik 1969, Normandeau 1970, Bader and Roessler 1971). Discharge water temperature at KNPP will not approach this level at any time.

A size-immotility relationship was observed for zooplankton passing through the condensers at KNPP (Figure 6.4 and Table 6.7). Entrained organisms which exceeded 1.4 mm in length (e.g. *E. lacustris* and *Daphnia retrocurva*) had a 11.9% higher immotility than non-entrained organisms, while organisms 0.4 mm or less (e.g. nauplii, cyclopoid copepodites and *B. longirostris*) had only 7.1% greater immotility. Linear regression analyses showed that immotility of entrained zooplankton was a function of species size, indicating that mechanical damage is an important factor in evaluating the effects of condenser passage on a given zooplankton population. Intake-discharge studies at Waukegan and Zion Stations

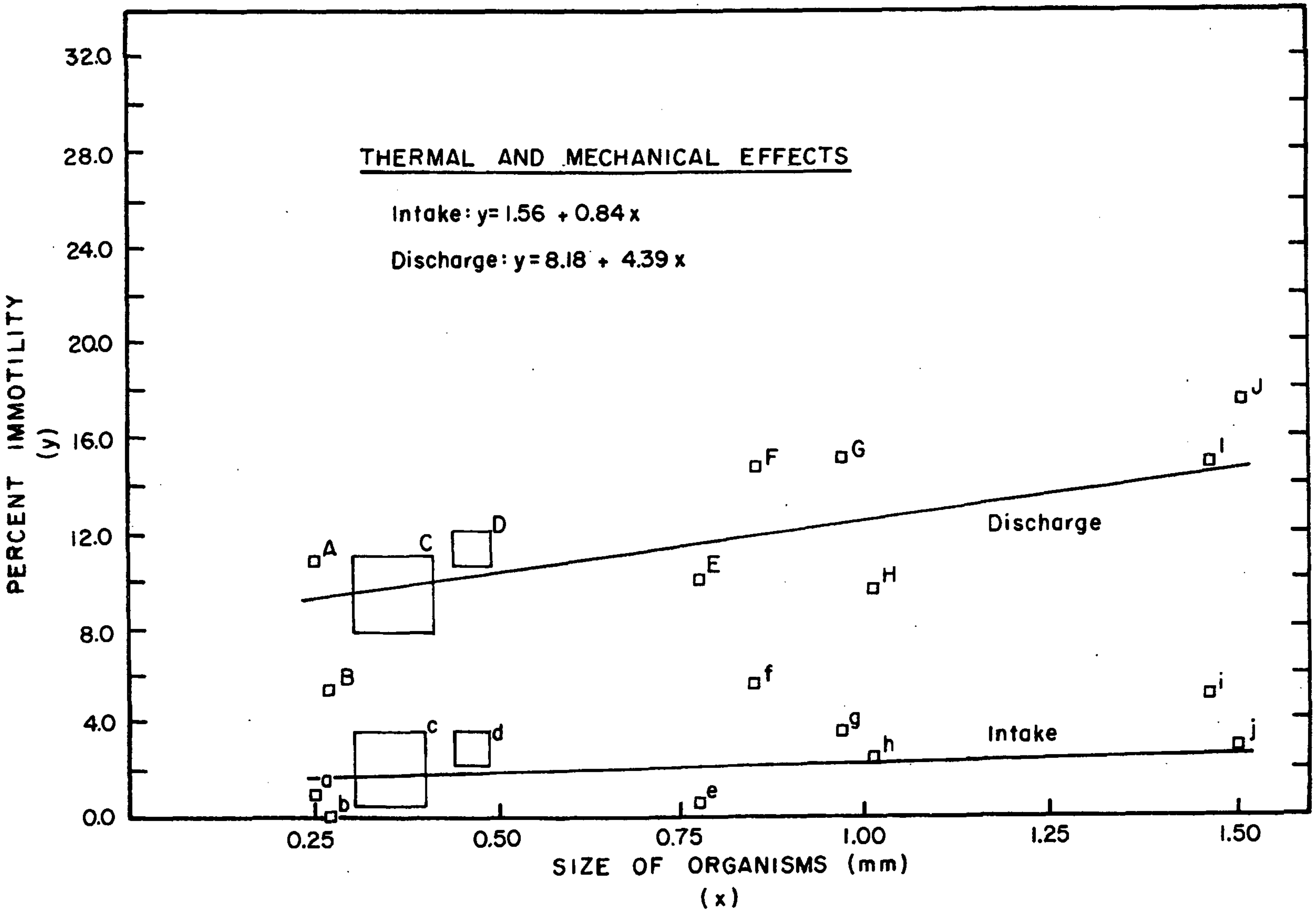

Figure 6.4 Linear regression analysis (size vs immotility) of condenser passage effects on zooplankton at Kewaunee Nuclear Power Plant during January, February, and from April through November 1976. Letters represented by boxes are referenced in Table 6.7. Capital letters indicate those organisms collected at the discharge and small letters indicate those organisms collected at the intake. Size of box denotes the population proportions among species.

Table 6.7. Zooplankton length measurements of dominant organisms collected at Kewaunee Nuclear Power Plant during January, February, and from April through November 1976.

Organisms	Symbol	Mean Size (mm)	Range (mm)	Reference
nauplii	A[a]	0.25	0.15-0.35	Gannon 1971 (personal communication)
Chydorus sphaericus	B	0.27	0.24-0.30	Gannon 1971 (personal communication)
Bosmina longirostris	C	0.34	0.28-0.42	Gannon 1971 (personal communication)
cyclopoid copepodite	D	0.47	0.35-0.58	Gannon 1971 (personal communication)
Cyclops bicuspidatus thomasi	E	0.78	0.57-0.96	Gannon 1971 (personal communication)
Diaptomus minutus	F	0.85	0.78-0.90	Wells 1970
Diaptomus ashlandi	G	0.95	0.90-1.00	Wells 1970
Diaptomus oregonensis	H	1.10	1.00-1.20	Gannon 1971 (personal communication)
Epischura lacustris	I	1.45	1.10-2.00	Gannon 1971 (personal communication)
Daphnia retrocurva	J	1.50	1.30-3.00	Brooks 1959

[a] Symbol used for Figure 6.4.

have demonstrated similar size-immotility relationships (Industrial BIO-TEST Laboratories, Inc. 1972 and Restaino et al 1975).

When KNPP was operating with (9.0 C ΔT) and without (no ΔT) heat exchange across the condensers, from March 1973 throug December 1974, an estimated 2.9% immotility was attributed to thermal effects and 5.9% immotility due to mechanical effects (Wetzel and Restaino 1974 and Wetzel 1975). Assuming similar conditions (mean ΔT = 10.3 C) thermal effects would have contributed only 33% of the total zooplankton immotility in 1976. Entrainment studies at Waukegan and Zion Stations showed that thermal effects resulted in only 23% and 4%, respectively, of the total zooplankton immotility.

D. Plume Entrainment

The effect of the heated discharge on zooplankton entrained in the plume was an increase in immotility relative to the control locations (Locations E-0 and E-5) (Table 6.6). However, zooplankton did not appear to be adversely affected by plume entrainment. Zooplankton immotility at the plume location (Location E-3) nearest the Plant was lower than at the discharge (Location E-2) on six of nine sampling dates. Zooplankton immotility at Location E-3, where water temperatures ranged from 4.2 C to 7.5 C above ambient, averaged 4.6% higher than the control immotility. Near the farthest extent of the plume (Location E-4), where water temperatures ranged from 1.4 C to 3.0 C above ambient, zooplankton immotility (2.6%) was only slightly higher than those at the control Loca tions E-0 and E-5. Zooplankton immotility at Location E-4 was sign ficantly higher than at the control locations on only one of seven sampling dates (Table 6.5).

Zooplankton mortality, four hours after condenser passage, increased slightly at all locations. Plume mortality averaged 12.8% at Location E-3 and 9.0% at Location E-4, whereas control Locations E-0 and E-5 averaged 5.9% and 5.4%, respectively. Zooplankton mortality measured in the plume decreased on seven of eight sampling dates as plume temperatures approached ambient.

IV. Summary and Conclusion

1. Entrained zooplankton (microcrustacea) population densities ranged from 160/m^3 in May to 70379/m^3 in September and averaged 13635/m^3 during 1976.

2. Copepoda were more abundant than Cladocera in all months except July and September through November when B. longirostris comprised 63% of the zooplankton community.

3. The combined thermal and mechanical effects of condenser passage on zooplankton resulted in immotilities ranging from 1.4% to 14.4% and averaging 8.9%. Approximately 33% of the total zooplankton immotility was attributed to thermal effects.

4. Condenser mortality, four hours after entrainment, average 8.8% with no clear indication of delayed mortality or recovery from the immediate effects (0 hrs) of condenser passage.

5. Immotility following condenser passage was correlated directly with species size but was apparently unrelated to the presence or magnitude of the discharge water temperature, indicating that mechanical factors were primarily responsible for the observed effects.

6. Since zooplankton immotility and mortality did not appear to increase during plume entrainment, the effects of prolonged entrainment within the immediate discharge area was negligible.

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NALCO ENVIRONMENTAL SCIENCES

Chapter 7

PERIPHYTON

Chris C. Altstaetter and Julie A. Heffelfinger

OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR
KEWAUNEE NUCLEAR POWER PLANT

SIXTH ANNUAL REPORT
January-December 1976

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NALCO ENVIRONMENTAL SCIENCES

Chapter 7

PERIPHYTON

Chris C. Altstaetter and Julie A. Heffelfinger

I. Introduction

The periphytic algal community near Kewaunee Nuclear Power Plant (KNPP) was studied in 1976 as part of the ongoing thermal monitoring program. Data in this chapter are based on collections made during the third operational year of the Plant and are intended to define the possible impact of Plant thermal discharge on the periphytic algal community.

The objectives of this study were:

1. to identify and document species of periphytic algae native to the study area throughout the warm weather period;

2. to determine whether differences exist in the abundance of algal periphyton, biomass and chlorophyll a concentrations between locations under the influence of the thermal plume and control (reference) locations outside the plume area; and

3. to compare results obtained in 1976 with data previously collected as part of the preoperational and operational studies.

II. Field and Analytical Procedures

Samples of periphytic algae were collected on 18 May, 20 July, 21 September and 16 November 1976. Samples were collected from natural shoreline substrates (rock or cement slabs in the "smash" zone) from four locations near KNPP and from steel pilings lining the discharge structure at a fifth location (Figure 7.1). Fifteen samples were collected per location of which three samples were used for species enumerations, six samples were used for biomass analyses, and six samples were used for the determination of chlorophyll a concentrations.

Each sample for algal identification, enumeration and biovolume consisted of two scrapings from a measured (0.1 dm^2) area. Samples were immediately preserved in a solution of "M^3" preservative (Meyer 1971) after collection. Diatoms were cleaned with nitric acid, washed and diluted. Subsamples were withdrawn and mounted on slides using Hyrax mounting medium (Hohn and Hellerman 1963). Non-diatom samples were mixed in a Waring blender, diluted, and subsamples were prepared as semi-permanent mounts. All diatom and non-diatom samples for each sampling date were adjusted to the same dilution for all locations. This dilution allowed for an average of at least 500 individuals to be counted per replicate.

Species enumeration was conducted on a defined "unit" basis. All filamentous forms were counted as lengths of 10 μm equal to one unit. Two diatom valves were equal to one unit. All other algal forms, unicellular and colonial, were counted as each individual or colony equal to one unit.

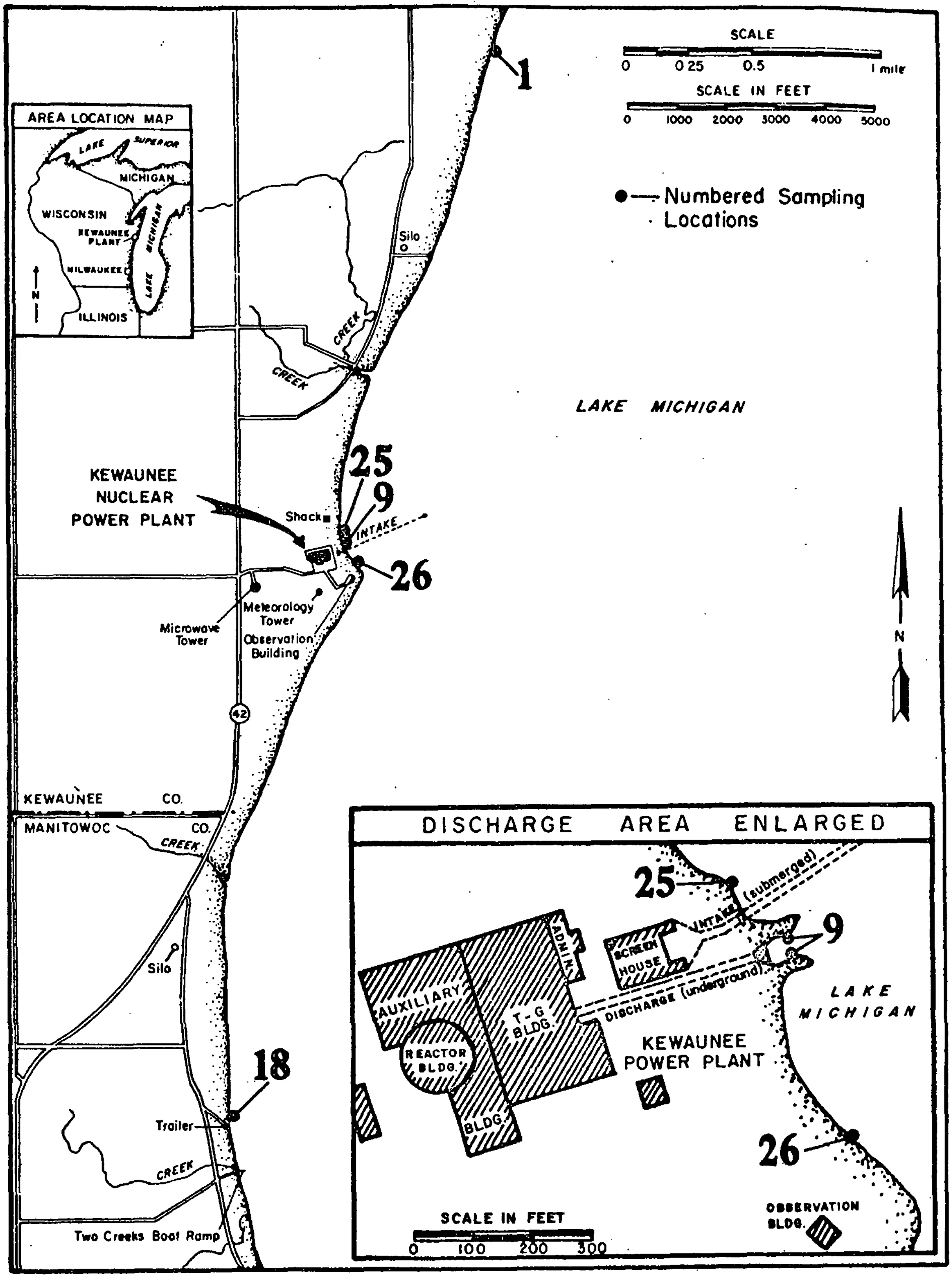

Figure 7.1. Periphyton sampling locations in western Lake Michigan near Kewaunee Nuclear Power Plant, 1976.

Biovolume was calculated using the geometrical configuration that best suited the respective taxon (Vollenweider 1969) and expressed as microliters per square decimeter ($\mu l/dm^2$). Taxonomic keys used included Hohn and Hellerman (1963), Huber-Pestallozzi and Hustedt (1942), Hustedt (1930), Patrick and Reimer (1966 and 1975), Prescott (1962), Smith (1950) and Tiffany and Britton (1952).

Each sample for biomass or chlorophyll a analyses consisted of material scraped from a measured (0.1 dm^2) area and was processed in accordance with A.P.H.A. et al. (1971). Biomass was reported as milligrams ash-free dry weight per square decimeter (mg/dm^2) and chlorophyll a was reported as micrograms per square decimeter ($\mu g/dm^2$).

Species diversity (Shannon 1948) and evenness indices were calculated and used to estimate the difference in community structure among sampling locations.

Reference to "dominant" algal taxa in the subsequent discussion refers to taxa that composed 5% or more of the mean total enumeration or mean total biovolume.

During May only samples for species identification, enumeration and biovolume were taken at Locations 25 and 18 and no samples were taken for biomass or chlorophyll. This was due to the lack of sufficient visible algal growth on the substrates for the total compliment of all samples. Likewise no samples were taken at Location 1 in November as ice covered all the available substrates.

III. Results and Discussion

A. Periphyton Community Composition

The periphytic algal community during 1976 was composed of 142 taxa distributed among four divisions: Chlorophyta (green algae), Bacillariophyta (diatoms), Cyanophyta (blue-green algae) and Rhodophyta (red-algae). Data from the analysis of samples, including species identification, enumeration numbers/cm^2) and biovolume (μl/dm^2) are presented in Appendix 7-A.

Members of the division Chlorophyta most often dominated the shoreline periphyton community. Species of Ulothrix were predominant during May, whereas, Cladophora glomerata was dominant during September and November (Figure 7.2). A similar seasonal dominance by these two taxa was also reported during previous studies in the vicinity of KNPP (Delinck 1974; Altstaetter 1975a, 1976) and in other areas of Lake Michigan (Altstaetter 1974, 1975b; Herbst 1969; Neil and Owen 1964; Taft 1975). The seasonal separation of these species was partially due to their different temperature optima. Ulothrix zonata, the most common species of Ulothrix encountered near KNPP, grows best at water temperatures below 15 C (Blum 1956). Cladophora glomerata reportedly grows best at water temperatures of approximately 18 C (Storr and Sweeny 1971), although it has also been observed growing vigorously at water temperatures of 7 C to 15 C (Herbst 1969).

There was some variability in the seasonal dominance of Ulothrix and C. glomerata among the North (1), South (18) and near the discharge (25 and 26) locations. One of the reasons for this

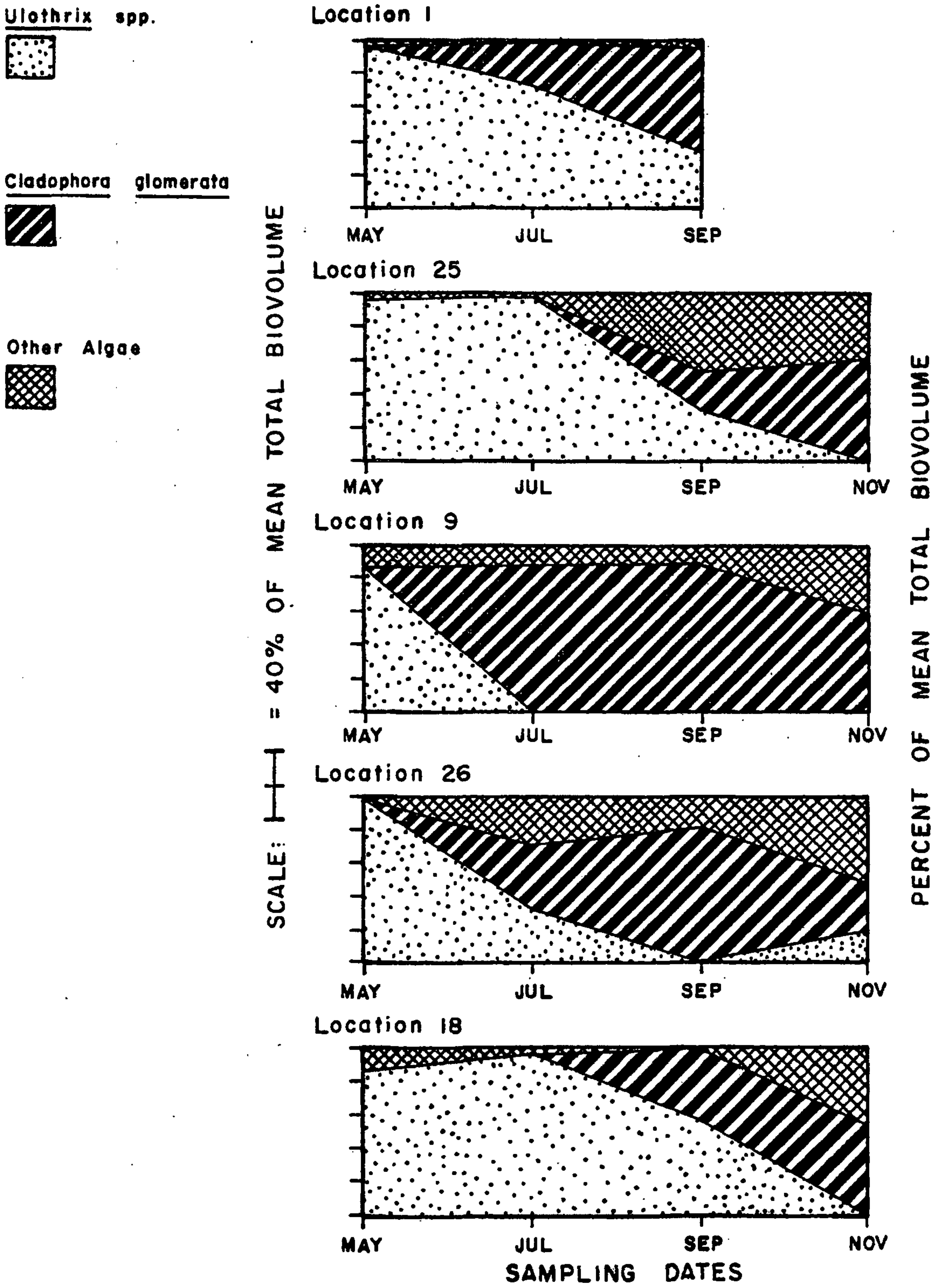

Figure 7.2. Percent of mean total biovolume of Ulothrix and Cladophora from periphytic algal samples collected near Kewaunee Nuclear Power Plant, May-November 1976.

variability was the presence of abundant populations of Bangia atropurpurea (a red alga) at Locations 25 and 26 during September and November and also at Location 26 during July. Bangia atropurpurea is a common competitor with Ulothrix and Cladophora for the splash zone shoreline community. Similar dominance patterns were reported in previous periphyton studies near KNPP (Altstaetter 1976) and in other areas of Lake Michigan (Altstaetter 1975b; Taft 1975). The presence of B. atropurpurea at Locations 25 and 26 and not at the other locations was probably a result of substrate orientation or suitability (NALCO Environmental Sciences 1976).

Other factors which cause variability in the Ulothrix - Cladophora assemblages among locations are successional growth patterns which occur after substrate scouring and species zonation exhibited by shoreline periphyton growth. These factors have been previously identified and discussed near KNPP (NALCO ES 1976).

The periphyton assemblage in the discharge canal (Location 9) was more often dominated by C. glomerata than at other locations (Figure 7.2). This may have been a result of warmer water in the discharge canal than at the other locations; however, Ulothrix dominated the discharge canal assemblage through July 1975 (Altstaetter 1976) rather than Cladophora as was the case in July 1976. It is suspected that this resulted from a competitive advantage of Cladophora over Ulothrix once the former became established. Cladophora has been shown to maintain itself in a reduced vegetative state (tufts) during periods which are not considered prime growth periods. As conditions become favorable these small tufts, which have been in a reduced state of activity, begin to flourish or "bloom" into the beds or mats which have become common to the Great Lakes (Taft 1975). It should be noted that although _Cladophora_ was a relatively early dominant in the discharge canal (as a percentage of the total biovolume), the discharge canal standing crop was relatively smaller than those recorded at the other locations. This subject will be further discussed in Section B of this report.

Diatoms were the second most common periphytic algal group encountered at the locations bracketing KNPP. _Fragilaria vaucheriae_ and _F. pinnata_ were the most common dominants and were accompanied by occasional dominant populations of _Gomphonema olivaceum_, _Rhoicosphenia curvata_, _Cocconies pediculus_ and _Achnanthes minutissima_. These species occurred typically at all locations and have been reported as major constituents of the diatom periphyton community during previous KNPP studies (NALCO ES 1976). These taxa have also been reported as common shoreline periphyton members of other areas of western Lake Michigan (Altstaetter 1975b; University of Wisconsin-Milwaukee 1971; Wisconsin Electric Power Company and Wisconsin Michigan Power Company 1973; Industrial BIO-TEST Laboratories, Inc. 1974). There were no consistent location-taxon correlations among the diatoms that would indicate a "preference" for any of the locations.

Results of sample analyses indicated that diatoms reached peak abundance at all locations in November. This was also evident from the November field observations as the most visible periphyton were diatoms and the patches of Cladophora noted at each location were very heavily epiphytized with diatoms.

Blue-green algae were common constituents of the periphyton community at all locations. They often composed dominant populations in mean units/cm^2; however, as a result of their relative smaller size in relation to the other algae, they composed a much smaller percentage of the mean total biovolume. For example, total Cyanophyta composed 47.1% and 60.9% of the mean units/cm^2 at Location 18 in May and July respectively; however, their respective portion of the mean total biovolume amounted to only 10.2% and 1.5%. Blue-green algae composed at least 41% of the mean units/cm^2 and at least 6% of the mean total biovolume throughout the year at Location 9 (discharge canal). The blue-green algal portion of the standing crop (μl/dm^2) in the discharge canal was generally larger than that of other locations (Figure 7.3) and was probably a result of the canal's environment (i.e., constant current and thermal enrichment). Similar results were occasionally evident during the 1975 monitoring program (Altstaetter 1976).

Lyngbya aerugineo-caerulea was one of the most common species of blue-green algae encountered at all locations. This taxon was also a common dominant during previous studies near KNPP (NALCO ES 1976). The other more common taxa encountered were variously labeled Phormidium retzii, P. tenue and P. sp. 1, all small forms generally less than 3 μm in diameter. The taxonomy of the small blue-greens is very difficult to interpret and it is uncertain whether there were any consistent location-taxon correlations amongst these species.

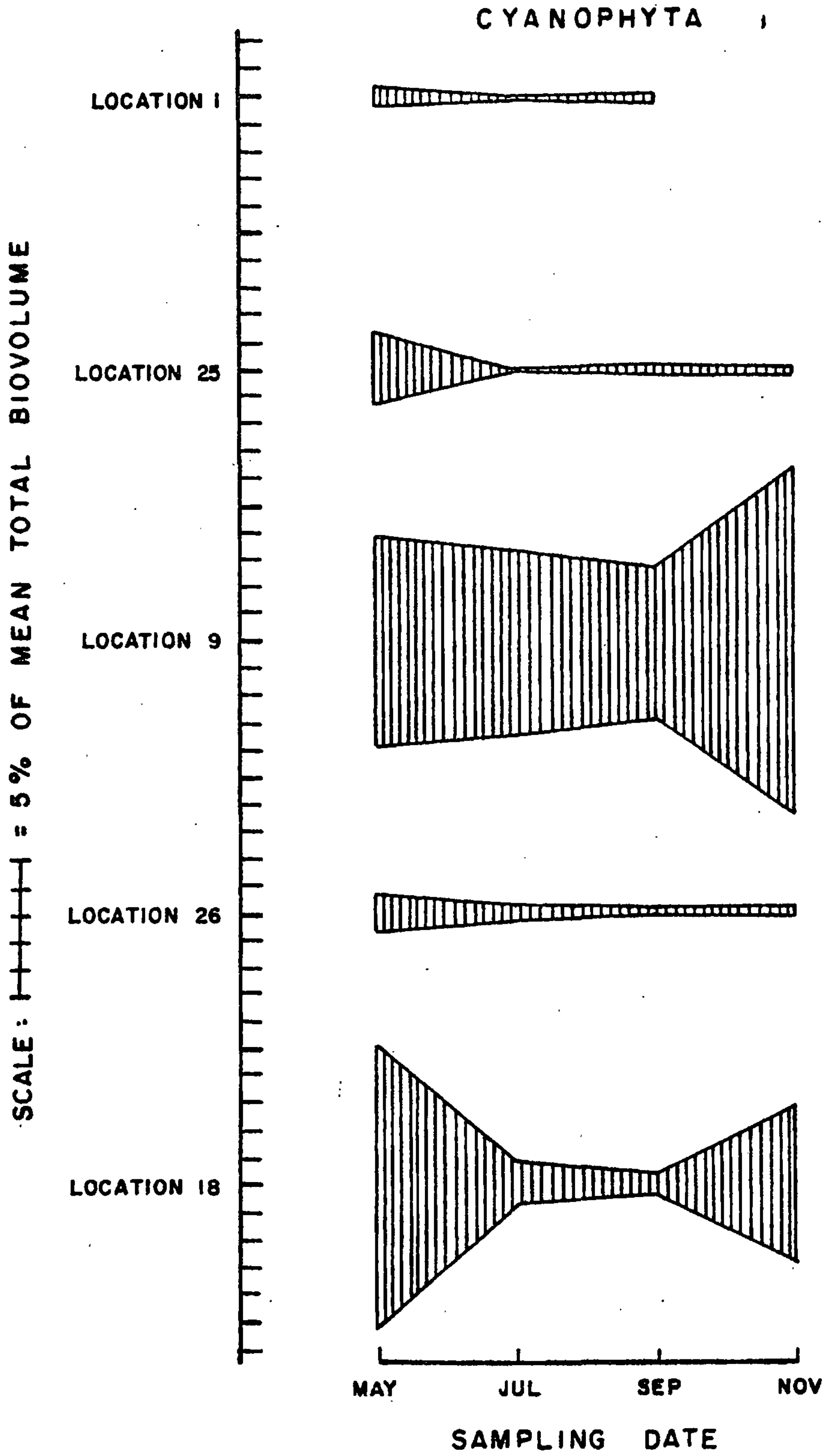

Figure 7.3. Percent of mean total biovolume of blue-green algae (Cyanophyta) from periphytic algal samples collected near Kewaunee Nuclear Power Plant, May-November 1976.

Species diversity tended to be higher at Locations 9 and 26, at the discharge canal and south of the discharge canal, respectively (Figure 7.1), except during the September collecting period (Table 7.1). In general, diversity was most often highest during September at all sampling locations. Highest diversity was found at Location 26 during July and at Locations 25 and 26 during September. As expected, species diversity values were generally low when a population was dominated by a single species. For example, during July at Location 25 _Ulothrix zonata_ composed 79.9% of the mean number of individuals and diversity and evenness equalled 1.34 and 0.24, respectively. Values were relatively high when the assemblages were balanced among diatoms, greens, and blue-greens. The observed trends may have been a function of favorable conditions at Locations 9 and 26 or proportionally more disfavorable conditions at the remaining locations, i.e., Locations 1, 25 and 18.

B. Periphyton Abundance

There was a general seasonal trend in the algal standing crop. A relatively smaller crop was encountered in May and the largest crop was usually encountered during July and September. There were some ranking differences over time among the biomass, chlorophyll _a_ and biovolume expressions of crop size (Figure 7.4). The variations among these three expressions of crop size are attributable to growth patterns, sampling differences, species shifts, etc., as discussed in earlier reports (NALCO ES 1976). Biovolume, biomass and chlorophyll _a_ values all fell within the expected range of those reported from previous studies (Altstaetter

Table 7.1. Number of species per location (S), species diversit (H) and evenness (E) of periphytic algae collected from natural substrates in Lake Michigan near Kewaunee Nuclear Power Plant, May-November 1976.

		Sampling Locations				
Sampling Date		1	25	9	26	18
18 May	S	39	35	42	31	41
	H	1.57	1.49	2.89	2.13	1.74
	E	0.30	0.29	0.54	0.43	0.32
20 July	S	29	49	61	65	33
	H	1.92	1.34	2.41	3.05	1.51
	E	0.40	0.24	0.41	0.51	0.30
21 September	S	34	43	43	65	41
	H	2.69	3.00	2.47	3.17	2.83
	E	0.53	0.55	0.46	0.53	0.53
16 November	S	[a]	31	26	29	25
	H		2.29	2.82	2.96	2.46
	E		0.46	0.60	0.61	0.53

[a] Not sampled due to ice covering all available substrates.

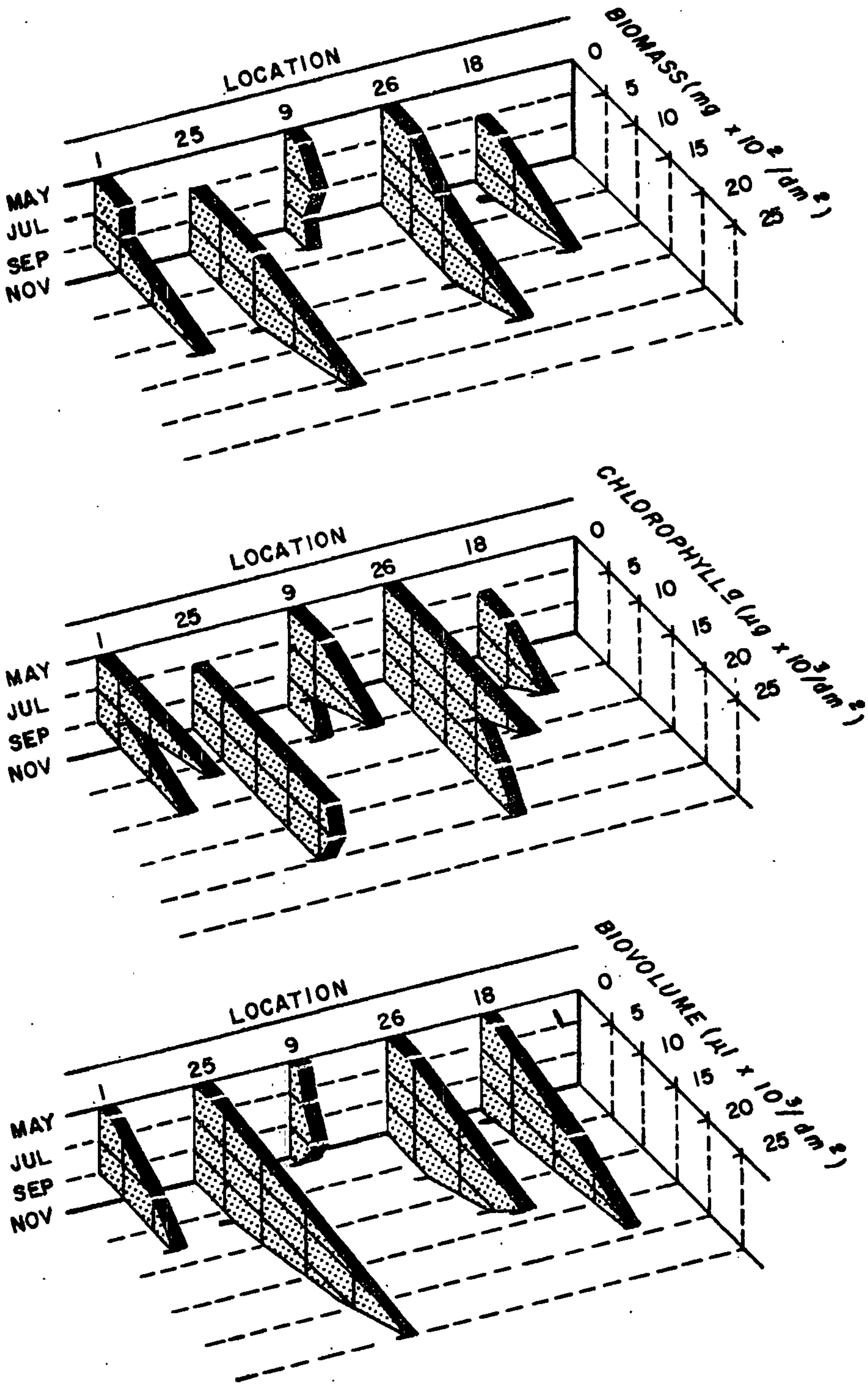

Figure 7.4. Mean biomass, mean chlorophyll a content and mean biovolume of periphytic algae from Lake Michigan near Kewaunee Nuclear Power Plant, May-November 1976.

1976). The periphyton standing crop in the discharge canal was generally lower than that recorded at the other locations. The constant current in the discharge canal probably maintained a fairly stable standing crop except when sloughing (caused by mechanical abrasion) occurred when the crop reached some maximum size.

III. Summary and Conclusions

1. The periphytic algal community during 1976 was composed of 142 taxa distributed among four divisions: Chlorophyta (green algae), Bacillariophyta (diatoms), Cyanophyta (blue-green algae), and Rhodophyta (red algae).

3. *Ulothrix* spp. and *Cladophora glomerata* (green algae) most often dominated the shoreline periphyton community and occasionally competed with *Bangia atropurpurea* (a red alga).

3. The seasonal variation of the green algae and the presence of the dominant diatoms and blue-green algae occurred typically at all locations.

4. The earlier seasonal presence of *Cladophora* in the discharge canal during July 1976 was inconsistent with the July 1975 *Ulothrix* domination. Whether or not this was a result of warmer waters in the discharge canal cannot be determined by available information.

5. Blue-green algae generally comprised a slightly larger portion of the standing crop in the discharge canal than at the other locations. This was probably a result of the canal's environment (i.e., constant current and thermal enrichment).

6. Mean total biovolume, mean biomass and mean chlorophyll *a* values from all locations fell within the expected range of those reported from previous studies.

7. The standing crop in the discharge canal was generally lower than those from the other locations. This was probably a result of the canal maintaining a fairly stable crop except when

sloughing (caused by mechanical abrasion) occurred when the crop reached some maximum size.

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NALCO ENVIRONMENTAL SCIENCES

Chapter 8

BENTHIC MACROINVERTEBRATES

Joseph H. Rains

OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR
KEWAUNEE NUCLEAR POWER PLANT

SIXTH ANNUAL REPORT
January - December 1976

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Chapter 8

BENTHIC MACROINVERTEBRATES

Joseph H. Rains

I. Introduction

This report describes the Lake Michigan benthic macroinvertebrate community adjacent to the Kewaunee Nuclear Power Plant (KNPP), Kewaunee, Wisconsin in 1976. Data presented in this report were obtained as part of a long range multidiscipline monitoring program to determine possible impact of the Kewaunee Nuclear Power Plant.

Specific objectives during this third year of Plant operation were:

1. to describe the species composition, abundance and seasonal variability of the benthic macroinvertebrate community during 1976;
2. to evaluate possible Plant effects by comparing data from locations inside and outside the area of thermal impact; and
3. to determine possible long range Plant effects by comparing operational and preoperational macroinvertebrate data.

II. Field and Analytical Procedures

A. Sampling Locations

Macroinvertebrate samples were collected from nine locations on 19 May, 22 July, 24 September and 18 November 1976 (Figure 8.1). Macroinvertebrate samples were collected at two loca tions along the 10 ft depth contour (Locations 6 and 11), four loca tions along the 20 ft depth contour (Locations 3, 7, 12 and 16) and three locations along the 30 ft depth contour (Locations 8, 13 and 17).

B. Immediate Discharge Area

The immediate discharge area (IDA) was defined as that portion of the lake bottom encompassed by the furthest extent of the 2 C excess temperature isotherm (Figure 8.1). This area was determined by vertical temperature profiles taken along the plume centerline under various weather conditions (NALCO Environmental Sciences 1976). Location 11 at the 10 ft depth was the only location within the IDA. Location 6 served as a control for Location 11. Locations at 20 and 30 ft depths were studied to detect any large-scale impacts.

C. Sample Collection and Analysis

Three replicate pump samples were collected from each location by a SCUBA diver. Substrate characteristics at each location during each sampling period were subjectively described from diver observations. The diver arbitrarily placed a one-eighth square meter metal frame on the lake botton in an area which had no rocks larger than one-third the area of the frame. A boat mounted

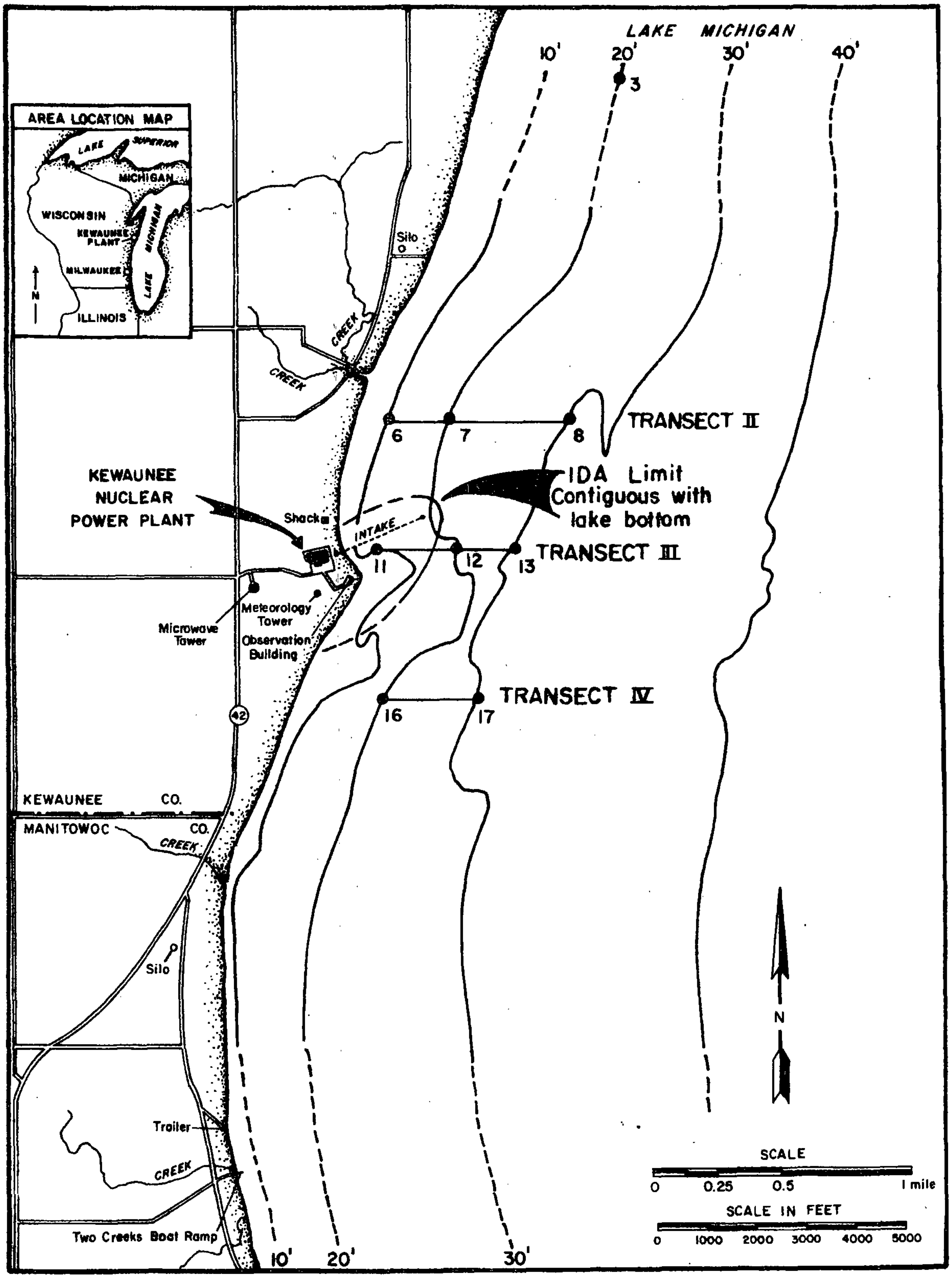

Figure 8.1. Benthic macroinvertebrate sampling locations and immediate discharge area (excess 2C temperature isotherm) near the Kewaunee Nuclear Power Plant in 1976.

variable speed, centrifugal pump with a 3 in diameter intake and 380 gpm capacity was used to convey the samples to the surface. The diver disturbed the sediments and scoured the rocks within the enclosed area while manipulating the pump intake hose to pick up the disturbed materials. Suspended material, i.e., the top 5-10 cm of silt and sand, and associated macroinvertebrates were conveyed to the surface and discharged into a No. 5 mesh (282 μm aperture) plankton net. The contents of the plankton net were rinsed into a plastic bag and preserved in 10% formalin.

The samples were transported to the laboratory and sieved on a U.S. Standard No. 30 mesh (595 μm aperture) sieve. Organisms retained on the sieve were rinsed into jars and stored in 75% ethanol.

All macroinvertebrate organisms were identified and enumerated with the aid of a binocular dissecting microscope, except Chironomidae and Oligochaeta. Chironomids and oligochaetes were sorted from the samples with the aid of binocular dissecting microscope, mounted and cleared in a non-resinous mounting medium and identified using a compound microscope with maximum magnification of 1000X. Density of all organisms was reported in numbers per square meter (No./m^2). All taxa and their densities are presented in Appendix 8A.

D. Taxonomy

The taxonomy of Oligochaeta followed that of Hiltunen (1967), Brinkhurst and Jamieson (1971) and Sperber (1950). Enchytraeidae, Lumbriculidae, Naididae and some Tubificidae were identified by external characteristics present at all stages of maturity. Other Tubificidae were identified by internal organs and structures present only when sexually mature. The tubificids identifiable at all stages of maturity were Potamothrix vejdovskyi and Tubifex ignotus. All other tubificids were identifiable only when mature and their immatures were classified as unidentifiable immature Tubificidae "with" or "without" capilliform chaetae.

Chironomid nomenclature generally followed that of Hamilton et al (1969). Identifications of representative chironomid specimens were verified by Dr. Ole A. Saether, Freshwater Institute, Winnipeg, Canada.

Other groups of organisms were identified using the following keys: Bousfield (1958), Burks (1953), Hamilton and Saether (1970), Harman and Berge (1971), Heard (1972), Hiltunen (1973), Lewis (1974), Pennak (1953), Roback (1957), Ross (1944), Saether (1973), Walter and Burch (1957), Wiggins (1960) and Williams (1972).

The availability of more descriptive and comprehensive taxonomic keys has led to more positive identifications of several taxa. This has resulted in five taxa which were present in 1973, being presented under different names during 1974-1976. The changes in nomenclature are as follows:

1973	1974-76
Oligochaeta	
Naididae	
Stylaria fossularis	Stylaria lacustris
Paranais litoralis	Uncinais uncinata

Trichoptera	
Phryganeidae	
Banksiola smithi	*Agrypnia* sp.
Diptera	
Chironomidae	
Procladius (S.S.) sp.	*Procladius* sp.
Procladius (*Psilotanypus*) sp.	

E. Statistical Analyses

A one-way analysis of variance (ANOVA) and Tukey's multiple comparison (Steel and Torrie 1960) were applied to estimated population densities of predominant taxa to determine significant ($P \leq 0.05$) differences between locations along the 20 and 30 ft dept contours. Student's "t" test (Steel and Torrie 1960) was utilized to determine significant ($P \leq 0.05$) differences in abundance between the two 10 ft locations. Student's "t" test was used instead of ANOVA on data from the 10 ft locations because there were only two 10 ft locations and the ANOVA required a minimum of three observations.

Species diversity indices were calculated for each replicate on each collection date using Shannon's (1948) diversity formula to log base e.

III. Results and Discussion

A. 1976 Benthos Collections

1. The Benthic Environment

Although a variety of substrate types were encountered at the 10 ft depth contours, sand was the primary sediment (Table 8.1). Substrates at the 20 and 30 ft depth contours consisted basically of periphyton covered rocks, varying in size from gravel to boulders. Small patches of sand, clay, and detritus were interspersed among the rocks. The periphyton covering the rocks was qualitatively analyzed. Cladophora was the predominant constituent. Constant resuspension, shifting and scouring of the sand substrates along the 10 ft depth contour due to wave action and currents created a high amount of stress on the benthic community. In contrast, the rocks at the 20 and 30 ft depth locations provided a more stable environment.

The most important aspect of the benthic environment was the presence of Cladophora. Fluctuations in the benthic community often correlated with the fluctuations in Cladophora growth.

The seasonal distributional pattern of Cladophora was described by Taft (1975). "Cladophora overwinters as a prostate thallus or as short basal portions of the upright filaments in rock crevices. Growth is renewed in the spring at 5 C water temperature and reaches its greatest development on the beds at 18 C. The mass of filaments detach and follow longshore currents until the mass is driven ashore or is carried into deep water by descending currents. New growth from the remaining "stubs" results in a less prolific

Table 8.1. Visual observations of substrates encountered at benthic macroinvertebrate sampling locations in Lake Michigan near the Kewaunee Nuclear Power Plant in 1976.

Depth	Location	May	July	September	November
10 ft	6	Clay, Gravel	Sand, Algae	Sand	Sand
	11	Clay, Rock[a], Gravel	Sand, Algae, Detritus	Sand	Sand, Gravel (Scoured Appearance)
20 ft	3	Rock	Rock	Rock	Rock
	7	Rock, Clay	Rock	Rock	Rock
	12	Rock, Sand	Clay, Detritus, Rock	Rock	Rock, Gravel
	16	Clay, Rock	Rock	Clay, Rock	Rock
30 ft	8	Clay, Rock	Rock	Rock	Rock
	13	Rock	Rock	Rock	Rock
	17	Clay, Gravel, Rock	Rock	Sand, Gravel	Rock, Sand

[a] All rocks encountered on all sampling dates were covered with varying amounts of Cladophora and associated diatoms.

summer population. Lower autumn temperatures result in a second large standing crop which in turn detaches as water temperatures decline toward 5 C." This growth pattern appeared to be similar to that at Kewaunee. Detached filamentous masses of Cladophora along the 10 ft depth contour in July were particularly influential on the benthic community.

2. Benthic Macroinvertebrate Community

A total of 114 macroinvertebrate taxa were identified in 1976. The taxonomic distribution of these taxa is presented in Table 8.2. Oligochaeta (worms) composed 40% of the total benthic macroinvertebrate community in terms of total number of individuals. Principal oligochaetes were the naidids Nais sp., Stylaria lacustris and Vejdovskyella intermedia and the tubificids Limnodrilus hoffmeisteri, L. angustipenis, Potamothrix moldaviensis, and P. vejdovskyi. The second most abundant group was Chironomidae (midges), which represented 20% of the total benthic macroinvertebrate community in terms of total numbers. Principal midges included Dicrotendipes sp., Heterotrissocladius sp., Microtendipes sp., and Thienemannimyia Series.

Amphipods, gastropods, nematodes and ostracods composed the majority of the remaining benthos. Amphipods were comprised almost exclusively of Gammarus pseudolimnaeus and were restricted primarily to the locations that had a periphyton substrate. The amphipods Pontoporeia affinis and Hyalella azteca were collected sporadically. Pontoporeia affinis has been reported as the most prevalent benthic macroinvertebrate in several areas of the upper

Table 8.2. Benthic macroinvertebrates collected in Lake Michigan near Kewaunee Nuclear Power Plant in 1976.

- Porifera
  - Demispongia
    - Haplosclerina
      - Spongillidae
        - *Spongila fragilis* Leidy
- Cnidaria
  - Hydrozoa
    - Hydroida
      - Hydridae
        - *Hydra* sp. Linaeus
- Platyhelminthes
  - Turbellaria
    - Tricladida
      - Planariidae
        - *Dugesia tigrina* (Girard)
    - Rhabdocoela
- Acanthocephala
- Aschelminthes
  - Nematoda
- Bryozoa
  - Gymnolaemata
    - Ctenostomata
      - Paludicellidae
        - *Paludicella articulata* (Ehr.)
  - Phylactolaemata
    - Plumatellina
      - Plumatellidae
        - *Fredericella* sp. Gerris
        - *Cristatella mucedo* Cuvier
- Mollusca
  - Gastropoda
    - Pulmonata
      - Lymnaeidae
        - *Lymnaea* sp.[a] Lamarck
      - Physidae
        - *Physa* sp. Draparnaud
      - Planorbidae
        - *Gyraulus deflectus* (Say)
        - *G. parvus* (Say)
    - Ctenobranchiata
      - Pleuroceridae
        - *Goniobasis livescens* (Menke)
      - Hydrobiidae
        - *Amnicola limosa* (Say)
        - *Amnicola* sp. Gould and Halderman

Table 8.2. (continued)

- Valvatidae
  - *Valvata perdepressa* Walker
  - *V. sincera* Say
  - *Valvata* sp. Muller
- Pelecypoda
  - Heterodonta
    - Sphaeriidae
      - *Pisidium* sp. Pfeiffer
      - *Sphaerium nitidum* Clessin
      - *S. striatinum* (Lamarck)
      - *Sphaerium* sp. Scopoli
- Annelida
  - Oligochaeta
    - Plesiopora
      - Enchytraeidae
      - Naididae
        - *Chaetogaster diaphanus* (Gruithuisen)
        - *Chaetogaster limnaei* Von Baer
        - *Nais behningi* Michaelson
        - *N. bretscheri* Michaelson
        - *Nais* sp. Muller
        - *Paranais frici* (Harbe)
        - *Piguetiella michiganensis* (Hiltunen)
        - *Slavina appendiculata* (d'Udekem)
        - *Stylaria lacustris*[b] (Linnaeus)
        - *Uncinais uncinata*[c] (Orstedt)
        - *Vejdovskyella intermedia* (Boetscher)
      - Tubificidae
        - *Ilyodrilus templetoni* (Southern)
        - *Limnodrilus angustipenis* Brinkhurst and Cook
        - *L. claparedeianus* Ratzel
        - *L. hoffmeisteri* Claparede
        - *L. hoffmeisteri* (variant) Claparede
        - *L. profundicola* (Verril)
        - *L. spiralis* Eisen
        - *L. udekemianus* Claparede
        - *Peloscolex freyi* Brinkhurst
        - *P. superiorensis* (Brinkhurst and Cook)
        - *Potamothrix bedoti* (Piguet)
        - *P. moldaviensis* Vejdovsky and Marzek
        - *P. vejdovskyi* (Herbe)
        - *Tubifex ignotus* (Stole)
        - *T. tubifex* Muller
    - Prosopora
      - Lumbriculidae
        - *Stylodrilus heringianus* Claparede
- Branchiobdellida

Table 8.2. (continued)

- Hirudinea
  - Rhynchobdellida
    - Glossiphoniidae
      - *Glossiphonia complanata* (Linnaeus)
      - *Helobdella stagnalis* (Linnaeus)
    - Pisicolidae
      - *Pisicola geometra* (Linnaeus)
  - Pharyngobdellida
    - Erpobdellidae
      - *Dina parva* Moore
- Arthropoda
  - Arachnida
    - Hydracarina
  - Crustacea
    - Ostracoda
    - Mysidacea
      - Mysidae
        - *Mysis relicta* Loven
    - Amphipoda
      - Haustoriidae
        - *Pontoporeia affinis* Lindstrom
      - Talitridae
        - *Hyalella azteca* (Saussure)
      - Gammaridae
        - *Gammarus pseudolimnaeus* (Bousfield)
    - Isopoda
      - Asellidae
        - *Asellus* sp. Geoffery St. Hillaire
        - *Lirceus* sp. Rafinesque
    - Decapoda
      - Astaecidae
  - Insecta
    - Ephemoroptera
      - Heptageniidae
        - *Heptagenia flavescens* (Walsh)
        - *Heptagenia* sp. Walsh
        - *Stenonema interpunctatum* (Say)
        - *S. tripunctatum* (Banks)
        - *Stenonema* sp. Traver
    - Trichoptera
      - Hydropsychidae
        - *Cheumatopsyche* sp. Wallengren
        - *Hydropsyche recurvata* Banks
        - *Hydropsyche* sp. Pictet
      - Phryganeidae
        - *Agrypnia* sp.[d] Curtis

Table 8.2. (continued)

- Lepidostomatidae
  - *Lepidostoma* sp. Rambur
- Leptoceridae
  - *Athripsodes* sp. Billberg
  - *Triaenodes* sp. McLachlan
- Coleoptera
  - Elmidae
    - *Dubiraphia* sp. Sanderson
- Diptera
  - Chironomidae
    - Tanypodinae
      - *Ablabesmyia* sp. Joh.
      - *Procladius* sp. (Skuse)
      - *Thienemannimyia* Series
    - Diamesinae
      - *Monodiamesa* sp. Kieff.
      - *Potthastia* sp. Kieff.
    - Orthocladiinae
      - *Corynoneura* sp. (Winn.)
      - *Cricotopus* sp. (V. d. Wulp)
      - *Eukiefferiella* sp. Kieff.
      - *Heterotrissocladius* sp. Spark
      - *Microcricotopus* sp.
      - *Parakiefferiella* sp. Thien.
      - *Pseudosmittia* sp. (Goefgh.)
      - *Synorthocladius* sp. Thien.
      - *Thienemanniella* sp. Kieff.
    - Chironominae
      - *Chironomus* sp. (Meigen)
      - *Cladotanytarsus* sp. Kieff.
      - *Cryptochironomus* sp. Kieff.
      - *Demicryptochironomus* sp. Lenz
      - near *Demicryptochironomus* sp.
      - *Dicrotendipes* sp. Kieff.
      - *Endochironomus* sp. Kieff.
      - *Micropsectra* sp. Kieff.
      - *Microtendipes* sp. Kieff.
      - *Parachironomus* sp. Lenz
      - *Paracladopelma* sp. Harn.
      - *Paralauterborniella* sp. Lenz
      - *Paratanytarsus* sp. Kieff.
      - *Phaenopsectra* sp. Townes
      - *Polypedilum* (s.s.) *convictum* type
      - *Polypedilum* (s.s.) *fallax* group Kieff.
      - *Polypedilum* (s.s.) *scalaenum* group Kieff.
      - *Polypedilum* (s.s.) *simulans* type

Table 8.2. (continued)

	Rheotanytarsus sp. (Bause) *Stictochironomus* sp. Kieff. *Tanytarsus* sp. V. d. Wulp
	Empididae

[a] *Lymnaea catascopium* and *L. humilis* reported in 1973 are now included in *Lynmaea* sp.

[b] *Stylaria fossularis* reported in 1973 are now included in *Stylaria lacustris*.

[c] *Paranais littoralis* reported in 1973 are now included in *Uncinais uncinata*.

[d] *Banksiola smithi* reported in 1973 are now included in *Agrypnia* sp.

Great Lakes (Eggleton 1936; Marzolf 1965; Alley 1968; and Brice 1975). *Pontoporeia affinis* is a burrowing amphipod which is most abundant in silty-sand substrates and least abundant in hard bottom substrates (Alley 1968). The rocky substrates at the 20 and 30 ft depth locations and the wave action at the 10 ft depth locations prohibited a large population of *P. affinis*.

Gastropods, which comprised only a small numerical fraction of the benthos, were represented principally by *Physa* sp. and *Lymnaea* sp. Little attention was directed toward either nematodes or ostracods due to inherent taxonomic difficulties and lack of adequate knowledge of their ecological significance.

The benthic community was subdividied into two broad, overlapping communities, which correlated with the substrate type. Although several taxa were common to both communities there was a distinction in percent occurrence of several taxa between the high-energy zone, sand-bottom community of the 10 ft contours, and the periphyton-macroinvertebrate association of the 20 and 30 ft contours.

Judd (1975) described a *Cladophora*-benthic macroinvertebrate association of inshore regions of lakes Erie and Ontario that was similar to the community at the 20 and 30 ft depth locations at Kewaunee. Amphipods, chironomids and oligochaetes comprised the majority of the community. Naidid oligochaetes increased in numbers during the summer months and amphipods and chironomids increased in density in the fall. Macroinvertebrate densities seemed to have been physically controlled by changing conditions in the Cladophora mats rather than regulated by active competition. The presence or absence of Cladophora also seemed to be highly influential on the benthic macroinvertebrate community structure at Kewaunee.

a. Ten Foot Contour

Sand substrates at the 10 ft depth contours (Locations 6 and 11) harbored a sparse benthic macroinvertebrate community composed primarily of naidid and tubificid oligochaetes, chironomids and ostracods (Tables 8.3 and 8.4). Oligochaetes averaged 1723 organisms/m^2 and represented an average of 43% of the total macroinvertebrate community at these two locations, i.e., 34% at Location 6 and 51% at Location 11. Principal oligochaetes were the naidids Piguetiella michiganensis, Uncinais uncinata, and Vejdovskyella intermedia and the tubificids Limnodrilus hoffmeisteri and Potamothrix moldaviensis. Naidid populations were sporadic with greatest densities occurring in July. Judd (1975) also found that greatest naidid densities in nearshore regions of Lake Ontario occurred during the summer. Chironomids averaged 1826 organisms/m^2 and represented an average of 23% of the benthic macroinvertebrate community at these two locations, i.e., 29% at Location 6 and 17% at Location 11. Predominant midges were Dicrotendipes sp., Paracladopelma sp. and Thienemannimyia Series.

The greatest density of most taxa occurred in July when settled clumps of detached Cladophora were sampled. Increased densities associated with clumps of algae were also noted in 1975 (Rains et al 1976). Other variations in substrate types

Table 8.3. Monthly and annual mean densities (organisms/m^2) and annual percent occurrences of principal benthic macroinvertebrates at Location 6 (10 ft depth) in 1976.

Taxa	May	July	September	November	Annual Mean	Percent Occurrence
Nematoda	43	69	115	3	57	2
Gastropoda	0	173	283	13	117	3
Oligochaeta						
Naididae						
Chaetogaster diaphanus	0	211	48	0	65	2
Nais sp.	0	301	5	0	77	2
Piguetiella michiganensis	11	163	8	416	150	4
Uncinais uncinata	13	155	0	0	42	1
Vejdovskyella intermedia	8	888	67	5	242	6
Tubificidae						
Limnodrilus hoffmeisteri	19	0	3	3	6	<1
Potamothrix moldaviensis	13	0	195	3	53	1
Unidentifiable Immature Tubificidae: With Capilliform Chaetae	8	3	155	0	42	1
Without Capilliform Chaetae	91	192	1581	24	472	13
Other Oligochaetae	42	143	255	2	109	3
Total Oligochaetae	205	2056	2317	453	1258	34
Ostracoda	227	2936	139	0	826	22
Amphipoda	16	16	443	11	122	3
Insecta						
Diptera						
Chironomidae						
Chironomus sp.	0	0	3	0	1	<1
Cricotopus sp.	101	248	3	24	94	3
Dicrotendipes sp.	0	142	1901	37	520	14
Heterotrissocladius sp.	0	136	3	0	35	1
Microcricotopus sp.	5	69	0	0	19	1
Paracladopelma sp.	5	152	0	184	85	2
Polypedilum fallax group	0	5	0	19	6	<1
Stictochironomus sp.	3	27	120	0	38	1
Tanytarsus sp.	5	24	115	0	36	1
Thienemannimyia Series	51	80	288	3	106	3
Other Chironomidae	73	330	164	56	156	4
Total Chironomidae	243	1213	2597	323	1094	29
Other Benthos	301	105	637	61	276	7
Total Benthos	1035	6568	6531	864	3750	

Table 8.4. Monthly and annual mean densities (organisms/m^2) and annual percent occurrences of principal benthic macroinvertebrates at Location 11 (10 ft depth) in 1976.

Taxa	May	July	September	November	Annual Mean	Percent Occurrence
Nematoda	53	256	96	5	103	2
Gastropoda	21	27	456	3	127	3
Oligochaeta						
Naididae						
Chaetogaster diaphanus	0	232	19	0	63	1
Nais sp.	0	376	13	0	97	2
Piguetiella michiganensis	11	11	1144	11	294	7
Uncinais uncinata	5	947	0	0	238	6
Vejdovskyella intermedia	0	933	200	0	283	7
Tubificidae						
Limnodrilus hoffmeisteri	211	88	0	29	82	2
Potamothrix moldaviensis	48	0	85	13	37	1
Unidentifiable Immature Tubificidae: With Capilliform Chaetae	16	13	136	11	44	1
Without Capilliform Chaetae	472	712	2163	325	918	21
Other Oligochaeta	218	133	152	24	132	3
Total Oligochaetae	981	3445	3912	413	2188	51
Ostracoda	125	2576	115	11	707	16
Amphipoda	35	21	285	19	90	2
Insecta						
Diptera						
Chironomidae						
Chironomus sp.	0	64	0	0	16	<1
Cricotopus sp.	149	40	0	3	48	1
Dicrotendipes sp.	3	26	907	53	247	6
Heterotrissocladius sp.	0	77	0	0	19	<1
Microcricotopus sp.	75	40	0	0	29	1
Paracladopelma sp.	0	109	3	179	73	2
Polypedilum fallax group	32	35	0	19	22	1
Stictochironomus sp.	11	24	43	3	20	<1
Tanytarsus sp.	48	13	77	0	33	1
Thienemannimyia Series	112	128	101	0	85	2
Other Chironomidae	106	161	197	90	139	3
Total Chironomidae	536	717	1328	347	732	17
Other Benthos	348	142	907	15	352	8
Total Benthos	2099	7184	7099	813	4299	

did not noticeably influence the benthic community. The scoured appearance at Location 11 in November may have been evident on previous sampling dates, however, poor visibility normally prevents visual observations of the benthic environment at the 10 ft depth contours. There was no appreciable benthic community alteration in the scoured area and no scouring effects were detected at the control (Location 6).

b. Twenty and Thirty Foot Contours

Although no 20 and 30 ft depth locations were within the IDA, data from these locations are useful in monitoring for possible wide-scale effects from Plant operation. The absence of appreciable wave action and the presence of the periphyton substrate at the 20 and 30 ft depth contours combined to produce a different community structure and greater macroinvertebrate density and diversity than at the 10 ft depth contour which supported a community indicative of the sand substrate. Oligochaetes were the principal macroinvertebrates (Tables 8.5-8.11). The tubificids *Limnodrilus angustipenis*, *L. hoffmeisteri*, *Potamothrix moldaviensis*, and *P. vejdovskyi*; the naidids *Nais* sp., *Stylaria lacustris* and *Vejdovskyella intermedia* (which are commonly associated with periphyton); and the lumbriculid *Stylodrilus heringianus* comprised nearly 90% of the oligochaetes. The most numerous midges were *Heterotrissocladius* sp., *Microtendipes* sp., and *Thienemannimyia* Series.

The *Cladophora*-macroinvertebrate association at the 20 and 30 ft contours presented a mixture of organisms which

Table 8.5. Monthly and annual mean densities (organisms/m^2) and annual percent occurrences of principal benthic macroinvertebrates at Location 3 (20 ft depth) in 1976.

Taxa	May	July	September	November	Annual Mean	Percent Occurrence
Nematoda	291	340	120	584	334	6
Gastropoda	557	764	1563	661	885	16
Oligochaeta						
Naididae						
Chaetogaster diaphanus	0	0	18	0	5	<1
Nais sp.	0	8	37	35	20	<1
Piguetiella michiganensis	0	0	0	0	0	0
Stylaria lacustris	29	212	43	0	71	1
Vejdovskyella intermedia	16	4	13	5	10	<1
Tubificidae						
Limnodrilus angustipenis	37	28	3	37	26	<1
L. hoffmeisteri	53	56	0	3	28	1
Potamothrix moldaviensis	37	28	11	64	35	1
P. vejdovskyi	19	44	24	16	26	<1
Unidentifiable Immature Tubificidae: With Capilliform Chaetae	88	108	61	104	90	2
Without Capilliform Chaetae	352	584	635	1899	868	16
Lumbriculidae						
Stylodrilus heringianus	112	120	157	424	203	4
Other Oligochaeta	68	48	19	66	50	1
Total Oligochaeta	811	1240	1021	2653	1431	27
Ostracoda	421	712	61	312	377	7
Amphipoda	184	1148	405	349	522	10
Insecta						
Diptera						
Chironomidae						
Cricotopus sp.	192	0	3	5	50	1
Dicrotendipes sp.	94	8	184	45	83	2
Heterotrissocladius sp.	6	72	5	371	114	2
Microtendipes sp.	187	132	243	667	307	6
Parakiefferiella sp.	200	16	0	29	61	1
Polypedilum fallax group	85	160	0	3	62	1
Stictochironomus sp.	19	4	67	28	30	1
Tanytarsus sp.	5	0	48	216	67	1
Thienemannimyia Group	357	536	91	139	281	5
Other Chironomidae	338	172	111	502	281	5
Total Chironomidae	1483	1100	752	2005	1088	20
Other Benthos	426	652	339	529	487	9
Total Benthos	4173	5956	4261	7093	5371	

Table 8.6. Monthly and annual mean densities (organisms/m^2) and annual percent occurrences of principal benthic macroinvertebrates at Location 7 (20 ft depth) in 1976.

Taxa	May	July	September	November	Annual Mean	Percent Occurrence
Nematoda	187	213	392	277	267	3
Gastropoda	64	261	445	605	344	4
Oligochaeta						
Naididae						
Chaetogaster diaphanus	0	40	459	0	125	1
Nais sp.	0	13	11	0	6	<1
Piguetiella michiganensis	0	40	0	0	10	<1
Stylaria lacustris	16	387	101	0	126	1
Vejdovskyella intermedia	13	850	85	13	242	3
Tubificidae						
Limnodrilus angustipenis	5	0	0	24	7	<1
L. hoffmeisteri	264	192	120	67	161	2
Potamothrix moldaviensis	83	8	83	299	118	1
P. vejdovskyi	19	19	69	88	49	1
Unidentifiable Immature Tubificidae: With Capilliform Chaetae	141	531	3448	805	1231	13
Without Capilliform Chaetae	912	1376	10029	3429	3937	42
Lumbriculidae						
Stylodrilus heringianus	56	11	13	128	52	1
Other Oligochaeta	174	119	198	54	150	2
Total Oligochaeta	1683	3592	14616	4907	6200	67
Ostracoda	69	1253	1035	112	617	7
Amphipoda	256	245	235	731	367	4
Insecta						
Diptera						
Chironomidae						
Chironomus sp.	64	117	0	19	50	1
Dicrotendipes sp.	5	8	75	120	52	1
Heterotrissocladius sp.	0	179	0	128	77	1
Microtendipes sp.	64	29	29	355	119	1
Parakiefferiella sp.	264	0	0	53	79	1
Polypedilum fallax group	131	35	3	0	42	<1
Stictochironomus sp.	35	35	35	147	63	1
Tanytarsus sp.	8	8	69	192	69	1
Thienemannimyia Group	128	245	64	189	157	2
Other Chironomidae	160	704	194	346	351	4
Total Chironomidae	859	1360	469	1549	1059	11
Other Benthos	189	228	816	438	418	5
Total Benthos	3307	7152	18008	8619	9272	

Table 8.7. Monthly and annual mean densities (organisms/m^2) and annual percent occurrences of principal benthic macroinvertebrates at Location 8 (30 ft depth) in 1976.

Taxa	May	July	September	November	Annual Mean	Percent Occurrence
Nematoda	328	336	195	419	320	8
Gastropoda	53	589	1008	2531	1043	26
Oligochaeta						
Naididae						
Chaetogaster diaphanus	0	88	0	0	22	1
Nais sp.	0	0	177	11	47	1
Piguetiella michiganensis	0	0	0	5	1	<1
Stylaria lacustris	11	80	115	0	52	1
Vejdovskyella intermedia	8	13	0	0	5	<1
Tubificidae						
Limnodrilus angustipenis	37	11	3	53	26	1
L. hoffmeisteri	77	91	0	3	43	1
Potamothrix moldaviensis	8	43	3	8	16	<1
P. vejdovskyi	3	13	8	3	7	<1
Unidentifiable Immature Tubificidae: With Capilliform Chaetae	32	69	40	40	45	1
Without Capilliform Chaetae	347	1107	376	472	576	14
Lumbriculidae						
Stylodrilus heringianus	77	133	291	440	235	6
Other Oligochaeta	69	123	35	74	75	2
Total Oligochaeta	669	1771	1048	1109	1149	28
Ostracoda	139	379	83	224	206	5
Amphipoda	37	144	35	187	98	2
Insecta						
Diptera						
Chironomidae						
Cricotopus sp.	11	5	0	3	5	<1
Dicrotendipes sp.	3	5	11	53	18	<1
Heterotrissocladius sp.	5	259	3	336	151	4
Microtendipes sp.	30	3	261	624	230	6
Parakiefferiella sp.	200	0	0	19	55	1
Polypedilum fallax group	168	53	0	5	57	1
Stictochironomus sp.	27	0	64	72	41	1
Tanytarsus sp.	27	11	19	160	54	1
Thienemannimyia Group	51	136	27	272	122	3
Other Chironomidae	78	187	26	392	171	4
Total Chironomidae	600	659	411	1936	902	22
Other Benthos	176	247	324	650	349	9
Total Benthos	1992	4125	3104	7056	4069	

Table 8.8. Monthly and annual mean densities (organisms/m^2) and annual percent occurrences of principal benthic macroinvertebrates at Location 12 (20 ft depth) in 1976.

Taxa	May	July	September	November	Annual Mean	Percent Occurrence
Nematoda	144	459	493	344	360	4
Gastropoda	29	1312	1741	1243	1081	12
Oligochaeta						
Naididae						
Chaetogaster diaphanus	0	387	35	0	106	1
Nais sp.	0	37	88	3	32	<1
Piguetiella michiganensis	29	56	3	13	25	<1
Stylaria lacustris	8	1936	67	0	503	6
Vejdovskyella intermedia	0	2325	19	0	586	7
Tubificidae						
Limnodrilus angustipenis	5	8	67	43	31	<1
L. hoffmeisteri	219	45	0	5	67	<1
Potamothrix moldaviensis	56	67	77	120	80	1
P. vejdovskyi	19	51	8	19	24	<1
Unidentifiable Immature Tubificidae: With Capilliform Chaetae	75	253	99	176	151	2
Without Capilliform Chaetae	408	1667	1368	1717	1290	14
Lumbriculidae						
Stylodrilus heringianus	141	32	240	253	167	2
Other Oligochaeta	88	261	28	59	109	1
Total Oligochaeta	1048	7125	2099	2408	3170	36
Ostracoda	8	7037	320	123	1872	21
Amphipoda	48	363	395	515	330	4
Insecta						
Diptera						
Chironomidae						
Cricotopus sp.	43	181	0	13	59	1
Dicrotendipes sp.	5	80	155	315	139	2
Heterotrissocladius sp.	3	536	5	237	195	2
Microtendipes sp.	37	64	336	357	199	2
Parakiefferiella sp.	472	0	3	120	149	2
Polypedilum fallax group	203	216	3	19	110	1
Stictochironomus sp.	88	67	128	171	114	1
Tanytarsus sp.	5	64	197	280	137	2
Thienemannimyia Group	88	416	51	248	201	2
Other Chironomidae	80	632	237	491	360	4
Total Chironomidae	1024	2256	1115	2251	1662	19
Other Benthos	70	475	813	393	438	5
Total Benthos	2371	19027	6976	7277	8913	

Table 8.9. Monthly and annual mean densities (organisms/m^2) and annual percent occurrences of principal benthic macroinvertebrates at Location 13 (30 ft depth) in 1976.

Taxa	May	July	September	November	Annual Mean	Percent Occurrence
Nematoda	224	152	165	693	309	7
Gastropoda	11	213	1627	2184	1009	23
Oligochaeta						
Naididae						
Chaetogaster diaphanus	0	16	13	0	7	<1
Nais sp.	0	0	283	0	71	2
Piguetiella michiganensis	16	0	8	16	10	<1
Stylaria lacustris	0	24	24	0	12	<1
Vejdovskyella intermedia	0	11	27	0	10	<1
Tubificidae						
Limnodrilus angustipenis	0	19	3	83	26	1
L. hoffmeisteri	125	43	0	11	45	1
Potamothrix moldaviensis	29	16	11	29	21	<1
P. vejdovskyi	3	5	16	8	8	<1
Unidentifiable Immature Tubificidae: With Capilliform Chaetae	32	40	85	45	51	1
Without Capilliform Chaetae	443	344	1115	1280	796	18
Lumbriculidae						
Stylodrilus heringianus	21	61	203	557	211	5
Other Oligochaeta	174	106	33	75	97	2
Total Oligochaeta	843	685	1821	2104	1363	30
Ostracoda	13	179	136	184	128	3
Amphipoda	13	205	259	256	183	4
Insecta						
Diptera						
Chironomidae						
Cricotopus sp.	11	5	0	5	5	<1
Dicrotendipes sp.	0	8	35	77	30	1
Heterotrissocladius sp.	5	432	16	397	213	5
Microtendipes sp.	0	11	536	1069	404	9
Parakiefferiella sp.	96	3	0	37	34	1
Polypedilum fallax group	208	27	0	5	60	1
Stictochironomus sp.	0	0	75	85	40	1
Tanytarsus sp.	0	3	235	173	103	2
Thienemannimyia Group	16	80	27	200	81	2
Other Chironomidae	91	76	124	429	180	4
Total Chironomidae	427	645	1048	2477	1149	26
Other Benthos	34	134	571	590	332	7
Total Benthos	1565	2213	5627	8488	4473	

Table 8.10. Monthly and annual mean densities (organisms/m^2) and annual percent occurrences of principal benthic macroinvertebrates at Location 16 (20 ft depth) in 1976.

Taxa	May	July	September	November	Annual Mean	Percent Occurrence
Nematoda	85	296	384	285	263	3
Gastropoda	80	301	643	251	319	4
Oligochaeta						
Naididae						
Chaetogaster diaphanus	0	40	3	0	11	<1
Nais sp.	0	3	19	16	10	<1
Piguetiella michiganensis	0	0	11	0	3	<1
Stylaria lacustris	32	504	99	0	159	2
Vejdovskyella intermedia	3	712	80	51	212	2
Tubificidae						
Limnodrilus angustipenis	11	5	3	16	9	<1
L. hoffmeisteri	675	333	11	131	288	3
Potamothrix moldaviensis	173	128	83	435	205	2
P. vejdovskyi	35	77	19	40	43	<1
Unidentifiable Immature Tubificidae: With Capilliform Chaetae	432	872	1765	989	1015	12
Without Capilliform Chaetae	1504	2581	3600	3629	2829	32
Lumbriculidae						
Stylodrilus heringianus	52	21	99	77	62	1
Other Oligochaeta	574	316	29	75	249	3
Total Oligochaeta	3491	5592	5821	5459	5091	58
Ostracoda	117	1968	269	165	630	7
Amphipoda	400	629	467	360	464	5
Insecta						
Diptera						
Chironomidae						
Cricotopus sp.	107	117	0	16	60	1
Dicrotendipes sp.	6	229	80	131	112	1
Heterotrissocladius sp.	0	149	0	179	82	1
Microtendipes sp.	85	56	227	203	143	2
Parakiefferiella sp.	19	8	0	141	42	<1
Polypedilum fallax group	16	19	0	24	15	<1
Stictochironomus sp.	5	32	152	67	64	1
Tanytarsus sp.	16	24	288	592	230	3
Thienemannimyia Group	355	307	48	117	207	3
Other Chironomidae	223	1187	325	693	607	7
Total Chironomidae	832	2128	1120	2163	1561	18
Other Benthos	208	281	816	485	448	5
Total Benthos	5213	11195	9520	9168	8774	

Table 8.11. Monthly and annual mean densities (organisms/m^2) and annual percent occurrences of principal benthic macroinvertebrates at Location 17 (30 ft depth) in 1976.

Taxa	May	July	September	November	Annual Mean	Percent Occurrence
Nematoda	248	189	208	355	250	4
Gastropoda	29	384	4771	1952	1784	29
Oligochaeta						
Naididae						
Chaetogaster diaphanus	0	149	69	0	55	1
Nais sp.	0	0	691	0	173	3
Piguetiella michiganensis	29	3	8	3	11	<1
Stylaria lacustris	8	603	56	3	168	3
Vejdovskyella intermedia	8	307	8	0	81	1
Tubificidae						
Limnodrilus angustipenis	0	11	8	75	24	<1
L. hoffmeisteri	136	8	0	5	37	1
Potamothrix moldaviensis	40	16	27	3	22	<1
P. vejdovskyi	8	16	59	0	21	<1
Unidentifiable Immature Tubificidae: With Capilliform Chaetae	72	21	133	40	67	1
Without Capilliform Chaetae	427	243	1173	1147	748	12
Lumbriculidae						
Stylodrilus heringianus	37	96	0	181	79	1
Other Oligochaeta	214	58	80	47	100	2
Total Oligochaeta	979	1531	2312	1504	1582	26
Ostracoda	117	1251	525	104	499	8
Amphipoda	24	664	568	197	363	6
Insecta						
Diptera						
Chironomidae						
Cricotopus sp.	11	13	0	0	6	<1
Dicrotendipes sp.	3	13	283	5	76	1
Heterotrissocladius sp.	0	285	8	637	233	4
Microtendipes sp.	13	37	549	419	255	4
Parakiefferiella sp.	293	0	3	24	80	1
Polypedilum fallax group	328	80	0	11	105	2
Stictochironomus sp.	0	0	67	51	30	<1
Tanytarsus sp.	13	11	24	168	54	1
Thienemannimyia Group	85	211	112	88	124	2
Other Chironomidae	105	174	269	360	227	4
Total Chironomidae	851	824	1315	1763	1188	19
Other Benthos	69	482	1128	290	492	8
Total Benthos	2317	5325	10827	6165	6159	

possessed a wide variety of life histories and environmental requirements. Tubificid assemblages similar to the Kewaunee tubificid assemblage have often been recorded from areas sustaining moderate degrees of enrichment in sandy substrates containing significant amounts of silt (Hiltunen 1967, Brinkhurst and Jamieson 1971 and Stimpson et al. 1975). Chironomids observed in this investigation included forms common in both lotic and lentic situations with feeding habits which ranged from detritus feeders to predaceous types. Gastropods, which were a significant part of the macroinvertebrate community, on some occasions represented omnivorous grazers which are often found in association with algae and aquatic tracheophytes. The mayflies, Stenonema sp. and Heptagenia sp., though not abundant in this study, are typically obligate stream forms found clinging in crevices between and under rocks. On the basis of the diverse types of life histories represented, the extensive aufwuchs obviously provided an infinite number of microhabitats well suited to colonization by a great many macroinvertebrates.

B. Assessment of Thermal Effects

1. Comparison of 1975 Collections Inside and Outside the Discharge

No plant related differences in the benthic macroinvertebrate community were apparent from comparisons of composition, diversity and abundance among collections inside and outside of IDA. Plant related thermal effects would have been most readily determined along the 10 ft depth contour by comparing data from Location 11, which was within the IDA, to data from Location 6, which was beyond the affected area. Similar communities, predominated by area. Similar communities, predominated by naidids, tubificids and chironomids, were determined at both locations (Tables 8.3 and 8.4). Community structure, in terms of species composition and relative abundance of major groups, was nearly identical at both locations. Shannon's (1948) diversity index, which is calculated on the basis of number of species and abundance of individuals of each species, provided a means of comparing community structure. Diversity indices, computed on data from both 10 ft locations, were variable but had similar ranges (Table 8.12). Diversity indices were generally lower at the 10 ft locations than at the 20 and 30 ft locations; this reflected the unsuitability of the sandy shallow water environment for macroinvertebrates. Therefore ,any variations or possible effects seen in this area are the possible effects of substrate limitation on the community.

Application of the Student's "t" test, which compared the abundance of the predominant fauna, further substantiated the apparent empirical similarities between the two locations (Table 8.13). No consistent statistical differences in dominant taxa occurred between Locations 6 and 11 of the 10 ft depth contour Similarity in community structure based on the comparison of dominants, diversity indices, and statistical analyses between Locations 6 and 11 indicated no appreciable sinking plume effects. Sinking plume effects, such as earlier maturation or a shift in community structure to warmer water species, would have been detectable in May samples, but no alterations were present.

Table 8.12. Mean Shannon (1948) species diversity indices for benthic macroinvertebrates collected in 1976.

Depth	Location	May	July	September	November
10 ft	6	2.38	2.44	2.39	1.60
	11	2.94	2.19	2.52	2.12
20 ft	3	3.23	2.69	2.65	3.00
	7	3.08	2.57	2.74	3.06
	12	2.82	2.42	2.81	3.08
	16	2.89	2.79	2.81	3.08
30 ft	8	2.91	2.82	2.45	2.82
	13	2.47	2.74	2.74	2.83
	17	2.70	2.68	2.59	2.68

Table 8.13. Summary of Student's "t" test applied to benthic macroinvertebrate data for taxa which composed 5% or more of the total number of macroinvertebrates collected at the 10 ft depth contour in 1976 ($P \leq 0.05$).

Taxa	Monthly Differences			
	May	July	September	November
Rhabdocoela	IS[a]	IS	None	IS
Total Oligochaeta	None[b]	None	None	None
Total Naididae	None	None	None	None
Nais sp.	IS	None	IS	IS
Piguetiella michiganensis	IS	IS	None	None
Uncinais uncinata	IS	11>6	11>6	IS
Vejdovskyella intermedia	IS	None	IS	IS
Total Tubificidae	None	None	IS	None
Immature without capilliforms	IS	None	None	11>6
Limnodrilus hoffmeisteri	11>6	IS	IS	IS
Stylodrilus heringianus	11>6	IS	IS	IS
Ostracoda	None	None	IS	IS
Total Amphipoda	IS	IS	None	IS
Gammarus pseudolimnaeus	IS	IS	None	IS
Hydracarina	None	IS	IS	IS
Total Chironomidae	None	None	6>11	None
Cricotopus sp.	None	IS	IS	IS
Dicrotendipes sp.	IS	IS	6>11	None
Monodiamesa sp.	IS	IS	IS	None
Paracladopelma sp.	IS	IS	IS	None
Thienemannimyia Group	None	IS	IS	IS
Empididae	None	IS	IS	IS
Total Benthos	None	None	None	None

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[a] Represented less than 5% of total Benthos.
[b] Sufficient data for comparisons, but no significant differences.

2. Comparison of Operational and Preoperational Benthos Data

All data prior to June 1974 represent preoperational activities. Furthermore, benthos data collected prior to 1973 were excluded from comparisons with later years in this report because field and laboratory procedures were not standardized until 1973. Only data from Locations 6 and 11 are used for comparison purposes. Location 11 was the only location inside the IDA and Location 6 served as a control or reference location since it was the only location outside the IDA with similar characteristics.

Summarized ranking tables, based on annual mean percent occurrence and abundance, were used to compare principal taxa at Locations 6 and 11 (Tables 8.14 and 8.15). Complete ranking tables for all locations are presented in Appendix 7A. Despite inherent problems in annual means, they are useful in assessing long term changes in community composition. Taxa which did not compose 1% or more of the benthos at least once during 1973-1976 are not included in the ranking tables due to their sporadic occurrence.

Ostracods, nematodes, oligochaetes and chironomids composed the majority of the benthos at both 10 ft contour locations (Tables 8.14 and 8.15). Tubificids, comprised mainly of *Limnodrilus hoffmeisteri* and *Potamothrix modlaviensis*, and naidids, consisting primarily of *Chaetogaster diaphanus*, *Nais* sp., *Stylari lacustris*, *Piguetiella michiganensis*, and *Vejdovskyella intermedia*, constituted the majority of oligochaetes. Predominant chironomids were the psammobionts *Paracladopelma* sp. and near *Demicryptochironomus* sp.

Table 8.14. Annual mean percent occurrence and annual mean abundance of benthic macroinvertebrates, ranked according to percent occurrence, from Location 6, Lake Michigan near the Kewaunee Nuclear Power Plant, 1973-1976.

	1973		1974		1975		1976	
Taxa	%	Mean #/m^2	%	Mean #/m^2	%	Mean #/m^2	%	Mean #/m^2
Ostracoda	23.9	628	1.0	8	23.1	508	22.0	825
Unident. Immat. Tubificae Without Capilliforms	10.4	286	12.5	102	4.2	93	12.6	472
Nematoda	7.1	195	2.1	17	<1.0	17	1.5	57
Vejdovskyella intermedia	6.7	183	<1.0	4	1.3	28	6.5	242
Parakiefferiella sp.	6.2	170	3.4	28	<1.0	9	<1.0	10
Polypedilum (s.s.) *scalaenum* Type	4.8	131	7.9	64	<1.0	8	1.1	41
Paracladopelma sp.	4.5	125	19.7	161	1.3	28	2.3	85
Nais sp.	4.4	121	1.2	10	11.2	247	2.0	77
Unident. Immat. Tubificidae With Capilliforms	3.5	97	<1.0	2	<1.0	8	1.1	41
Thienemannimyia Group	3.4	94	1.0	8	2.1	47	2.8	105
Monodiamesa sp.	2.8	77	6.9	56	<1.0	10	<1.0	19
Microcricotopus sp.	2.0	56	1.2	10	1.1	24	<1.0	15
Hydracarina	1.5	41	1.2	10	<1.0	14	2.4	89
Limnodrilus hoffmeisteri	1.4	37	<1.0	5	<1.0	5	<1.0	6
Stylodrilus heringianus	1.3	37	<1.0	1	<1.0	7	<1.0	23
Polypedilum (s.s.) *fallax* Group	1.3	35	4.2	34	<1.0	14	<1.0	6
Piquetiella michiganensis	1.1	31	11.5	93	<1.0	2	4.0	149
Microtendipes sp.	1.1	29	<1.0	1	<1.0	14	<1.0	25
Uncinais uncinata	1.0	27	<1.0	7	6.1	135	1.1	42
Potamothrix moldaviensis	1.0	27	1.6	13	<1.0	5	1.4	53
near *Demicryptochironomus* sp.	<1.0	5	5.1	41	1.0	21	<1.0	2
Chironomus sp.	<1.0	9	5.0	41	<1.0	2	<1.0	1
Pontoporeia affinis	<1.0	11	2.1	17	<1.0	9	<1.0	5
Cricotopus sp.	<1.0	19	1.6	13	9.9	217	2.5	94
Heterotrissocladius sp.	<1.0	16	1.5	12	2.9	64	<1.0	35
Limnodrilus profundicola	<1.0	4	1.1	9	<1.0	1	<1.0	3
Tanytarsus sp.	<1.0	13	1.1	9	<1.0	17	1.0	36
Chaetogaster diaphanus	<1.0	7	0	0	15.4	339	1.7	65
Stylaria lacustris	<1.0	5	<1.0	1	5.7	126	1.2	45
Dicrotendipes sp.	<1.0	3	<1.0	2	2.1	45	13.9	519
Paratanytarsus sp.	<1.0	4	0	0	1.5	32	<1.0	14
Gammarus pseudolimnaeus	<1.0	12	<1.0	1	<1.0	9	3.0	113
Physa sp.	<1.0	1	0	0	0	0	2.9	110
Rhabdocoela	<1.0	8	<1.0	3	<1.0	4	2.2	83
Stictochironomus sp.	<1.0	2	0	0	<1.0	13	1.0	37
Empididae	<1.0	9	<1.0	6	<1.0	9	1.0	36

Table 8.15. Annual mean percent occurrence and annual mean abundance of benthic macroinvertebrates, ranked according to percent occurrence, from Location 11, Lake Michigan near the Kewaunee Nuclear Power Plant, 1973-1976.

Taxa	1973		1974		1975		1976	
	%	Mean #/m2	%	Mean #/m2	%	Mean #/m2	%	Mean #/m2
Unident. Immat. Tubificidae Without Capilliforms	11.2	79	11.0	306	33.7	314	21.4	918
Vejdovskyella intermedia	10.5	75	5.3	148	<1.0	5	6.6	283
near *Demicryptochironomus* sp.	10.4	73	<1.0	21	6.0	56	<1.0	7
Microtendipes sp.	6.7	47	3.1	85	1.0	9	<1.0	13
Parakeifferiella sp.	6.5	46	8.6	239	4.4	41	<1.0	12
Polypedilum (s.s.) *scalaenum* Type	5.0	35	5.2	145	1.0	9	<1.0	16
Polypedilum (s.s.) *fallax* Group	4.7	33	2.9	82	6.6	61	<1.0	21
Nematoda	4.3	31	1.5	43	3.3	31	2.4	103
Paracladopelma sp.	4.1	29	3.1	85	12.9	120	1.7	73
Thienemannimyia Group	4.0	28	1.6	45	<1.0	6	2.0	85
Monodiamesa sp.	2.6	19	1.5	41	3.1	29	<1.0	37
Chironomus sp.	2.4	17	1.2	34	<1.0	2	<1.0	16
Stylodrilus heringianus	2.4	17	<1.0	10	<1.0	3	<1.0	37
Gammarus pseudolimnaeus	2.3	16	<1.0	11	<1.0	2	2.0	85
Potamothrix moldaviensis	2.3	16	<1.0	21	1.4	13	<1.0	37
Hydracarina	2.1	15	1.5	43	1.9	17	3.6	155
Hydra sp.	1.3	9	3.2	89	1.0	9	<1.0	18
Rhabdocoela	1.1	8	3.1	86	1.0	9	2.2	93
Ostracoda	1.0	7	6.7	186	4.9	46	16.4	707
Hydropsyche sp.	1.0	7	<1.0	13	<1.0	1	<1.0	12
Pseudosmittia sp.	1.0	7	<1.0	7	<1.0	3	<1.0	3
Nais sp.	<1.0	3	12.3	343	<1.0	6	2.3	97
Paranais frici	0	0	5.1	143	0	0	0	0
Dicrotendipes sp.	0	6	3.2	89	1.8	17	5.7	247
Unident. Immat. Tubificidae With Capilliforms	<1.0	6	1.4	40	<1.0	7	1.0	44
Nais bretscheri	0	0	1.4	39	<1.0	5	<1.0	10
Cricotopus sp.	<1.0	1	1.4	39	<1.0	7	1.1	48
Heterotrissocladius sp.	0	0	1.3	39	<1.0	3	<1.0	19
Stylaria lacustris	<1.0	1	1.2	34	<1.0	2	<1.0	25
Uncinais uncinata	0	0	1.1	31	<1.0	1	5.5	238
Puqietiella michiganensis	0	0	<1.0	22	2.2	21	6.8	294
Empididae	<1.0	1	<1.0	7	2.1	20	1.1	46
Limnodrilus hoffmeisteri	<1.0	3	<1.0	25	1.7	16	1.9	82
Stictochironomus sp.	<1.0	6	<1.0	23	1.1	10	<1.0	20
Physa sp.	<1.0	2	<1.0	9	<1.0	3	1.9	81
Chaetogaster diaphanus	0	0	<1.0	3	<1.0	1	1.5	63

Other common chironomids were *Dicrotendipes* sp., *Microtendipes* sp., *Parakiefferiella* sp., *Polypedilum fallax* type, *Polypedilum scalaenu* type, and *Thienemannimyia* Series. All taxa at both 10 ft contour locations were very sporadic in percent occurrence and abundances over the four year period. No permanent alterations in community composition, due to Plant operation, were apparent. The highly fluctuating density of all taxa reflected the high stress environment afforded by the shifting sand substrates along the 10 ft depth contour.

IV. Summary and Conclusions

1. Two distinct substrate types were sampled near KNPP in 1976. Unstable, shifting sand substrates were prevalent at the 10 ft depth contour locations, and various sized rocks covered with varying amounts of *Cladophora* predominated at 20 and 30 ft depth contour locations.

2. Assemblages of oligochaetes and chironomids were the principal macroinvertebrates collected. Lesser numbers of nematodes, ostracodes, amphipods, gastropods and aquatic insects, other than midges, also occurred.

3. The total benthic community was subdivided into two broad overlapping communities which correlated with the substrate type. Principal components of the sand community of the 10 ft depth locations were the naidids *Piguetiella michiganensis*, *Unicinais uncinata*, and *Vejdovskyella intermedia*; the tubificids *Limnodrilus hoffmeisteri* and *Potamothrix moldaviensis*; the chironomids *Dicrotendipes* sp., *Paracladopelma* sp., and *Thienemannimyia* Series; and ostracods. Principal components of the 20 and 30 ft depth locations were the naidids *Nais* sp., *Stylaria lacustris*, and *Vejdovskyella intermedia*; the tubificids *Potamothrix moldaviensis*, and *P. vejdovskyi*; the lumbriculid *Stylodrilus heringianus*; and the midges *Heterotrissocladius* sp., *Microtendipes* sp., and *Thienemannimyia* Series.

4. Empirical comparisons of community structure and species diversity indices between locations inside (Location 11) and outside (Location 6) the Immediate Discharge Area indicated no evidence of effects on the macroinvertebrate community due to Plant operation.

5. Statistical comparisons of the abundance of predominant fauna between these locations further substantiated empirical evaluation.

6. Analysis of major taxa collected at Locations 6 and 11 from 1973 through 1976 indicated no long term permanent alterations in the benthic macroinvertebrate community due to Plant operation.

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Chapter 9

FISH POPULATION AND LIFE HISTORY

Larry J. LaJeone

OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR
KEWAUNEE NUCLEAR POWER PLANT

SIXTH ANNUAL REPORT
January - December 1976

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Chapter 9

FISH POPULATION AND LIFE HISTORY

Larry J. LaJeone

I. Introduction

This report is the sixth of a continuing study of the population and life history of fish species inhabiting Lake Michigan in the vicinity of the Kewaunee Nuclear Power Plant (KNPP). Data compiled for this report were collected during the third year of Plant operation.

The specific objectives of this study were:

1. to determine the species composition and relative abundance of fishes inhabiting Lake Michigan near KNPP;
2. to analyze the temporal and spatial distribution, and movements of fish in the vicinity of KNPP, particularly in area adjacent to the Plant intake and discharge;
3. to determine what segments of the life histories of species present are being conducted within the study area; and
4. to compare results of this 1976 operational study with the results of previous operational and preoperational studies to detect possible effects of Plant operation on the fish population.

II. Field and Analytical Procedures

Sampling locations for this fish study in Lake Michigan for 1976 were the same as those established for studies conducted from 1972 through 1975 (Industrial BIO-TEST Laboratories, Inc. 1973; LaJeone 1974, 1975, 1976). A map of the study area and fish sampling locations is given in Figure 9.1.

Fish were sampled by experimental gill net at Locations A, B and C on 28 April, 19 May, 16 June, 21 July, 25 August, 23 September, 20 October and 17 November. Gill net specificiations were the same as those used from 1973 through 1975. Each net consisted of four panels of different mesh sizes constructed as follows:

Net Length (feet)	Stretched Mesh Size (inches)	Twine Size	Phase Measure (inches)	Ties Between Leads	No. of Mesh on Each Tie	No. of Leads Per Net	Mesh Dept
50	1-1/2	210/2D.S	11	12	10	7	54
300	2-1/2	210/2D.S.	7-1/2	12	6	40	32
305	3-1/2	210/2D.S.	8-3/4	11	5	38	23
302	5-1/2	210/3D.S.	8-1/4	11	3	40	14

One net was set along the 15 ft depth contour at each location. Nets were set in the afternoon and retrieved the following morning for an average fishing time of approximately 20 hours. Surface and bottom water temperatures were recorded at each location prior to retrieval of nets using a Whitney TC-5A Thermistor thermometer.

Fish were collected by minnow seine at Locations 5, 9, and 19 on 27 April, 18 May, 14 June, 19 July, 24 August, 20 September, 18 October and 15 November. Specifications for the seine were the same as those from 1973 through 1975. Dimensions of the seine employed were 30 ft x 6 ft of 1/4 ince Ace mesh with a 6 ft x 6 ft bag of 1/8 inch Ace mesh. Two hauls were taken at each location, each haul

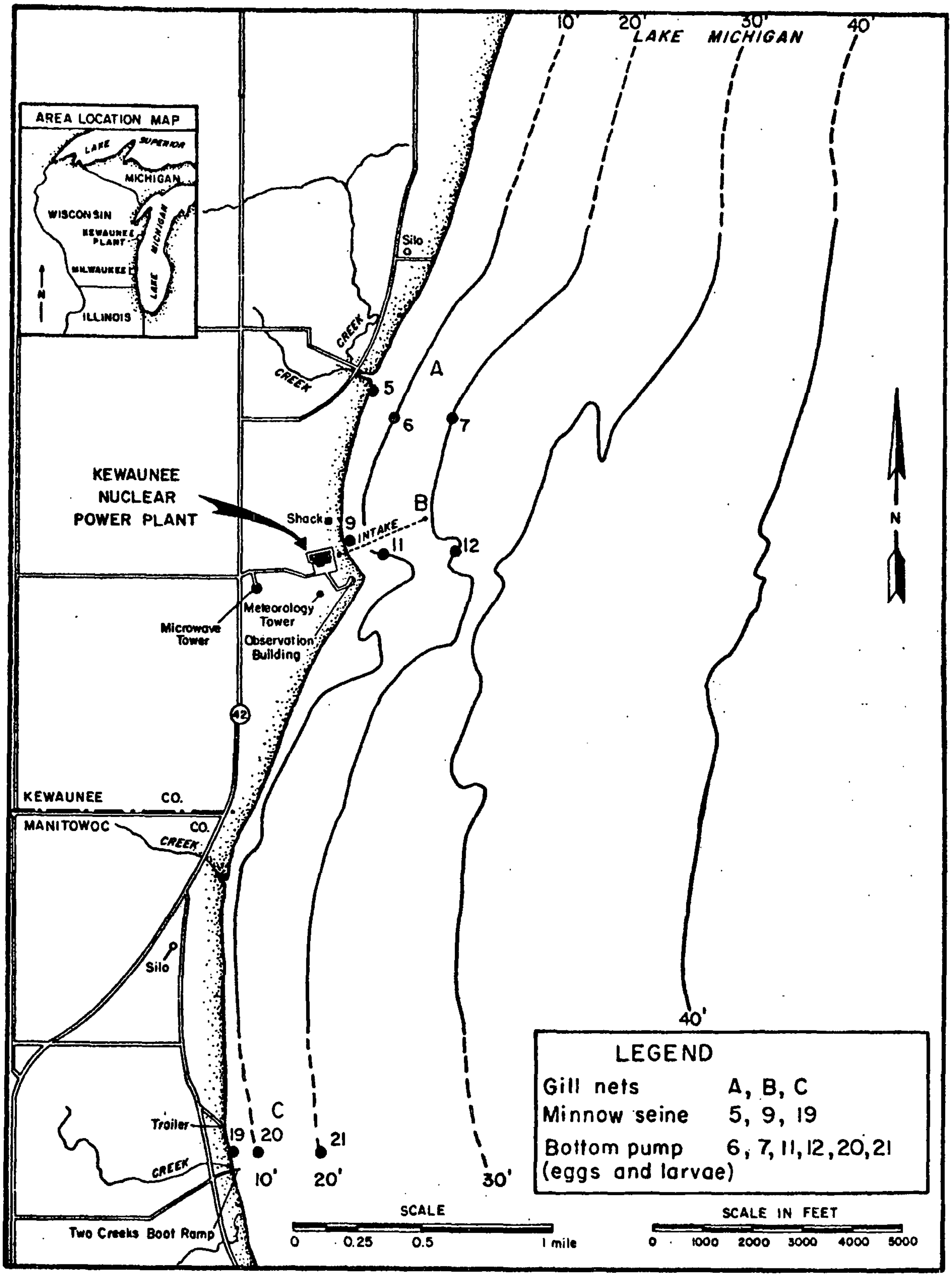

Figure 9.1. Fish sampling locations used in environmental monitoring studies at the Kewaunee Nuclear Power Plant during 1976.

covering approximately 100 ft of shoreline. Surface water temperatures were taken prior to sampling at each location.

Fish eggs and larvae were sampled using the Homelite suction pump described in Chapter 8 (Benthos). Sampling was conducted on 27 April, 19 May, 21 July, 24 September and 17 November at Locations 6, 7, 11, 12 and 21. The pump was operated for approximately three minutes at each location. The intake hose was drawn along the lake bottom as the boat drifted with the wind and current. Bottom material was collected by pumping into a No. 5 mesh (280 µaperature) Nitex plankton net.

All fish collected by gill net were processed in the field. The majority of fish collected by minnow seine were examined in the laboratory. All fish egg and larvae samples were processed in the laboratory.

All fish collected were identified to species. Sport and commercial species collected in suitable condition were tagged with anchor tags, measured for total length and returned to the lake in an attempt to monitor fish movements in the vicinity KNPP. All other fish collected were weighed in grams and measured in millimeters with the following exceptions: (1) extremely small fish were not weighed; and (2) when large numbers of an individual species were collected, a subsample of approximately 10% were weighed and measured, the remaining fish of the species being counted and weighe collectively. Condition factor was calculated for abundant, and valuable sport and commercial species according to Carlander (1969) as follows:

$$K^{tl} = \frac{W \times 10^5}{tl^3}$$

where: W = weight of fish in grams
tl = total length of fish in millimeters

Scale samples for age and growth analyses were taken from selected salmonids and yellow perch at various times throughout the study. Age group determinations were based on the number of years each fish had survived past 1 January. Stomachs were excised from selected specimens, preserved in 10% formalin and returned to the laboratory for content analysis. Food items were identified to the lowest positive taxon with percent frequency of occurrence and percent of total volume calculated for each category.

Representative individuals of all species collected were sexed and gonadal condition noted. Gonadal conditions of fish were described by the following five stages:

Stage I: Immature - Young individuals not yet engaged in reproduction, very small sexual organs close under the vertebral column, sex not usually apparent to the naked eye;

Stage II: Mature - Sexual organs well developed with eggs clearly discernible, testes reddish-white;

Stage III: Ripe - Sexual organs filling ventral cavity, testes white, gonads achieved maximum weight, but sexual products do not extrude even with light pressure;

Stage IV: Ripe and Running - Eggs or milt extrude with slight pressure, most eggs translucent; and

Stage V: Spent - Testes and ovaries empty, a few eggs in state of reabsorption, gonads have appearance of deflated sacs.

All fish eggs collected were identified, counted and the diameter measured. Larval and juvenile fish collected were identified and measured for total length.

III. Results and Discussion

A. Water Temperature

Bottom water temperatures recorded at gill net locations are given in Table 9.1. Temperatures ranged from 2.6 C at Location C on 17 November to 14.5 C at Location A on 23 September. Bottom water temperatures varied only slightly between sampling locations on any given sampling date, with the exception of temperatures recorded on 21 July and 17 November. On 21 July the bottom water temperature at Location C was 3.5 C warmer than at Location B, and on 17 November temperatures at Locations A and B were 1.6 and 2.6 C warmer, respectively, than that recorded at Location C. On all other sampling dates the temperature range between gill net locations was not greater than 0.6 C and on several occasions (19 May, 16 June, 21 July, 25 August) temperatures at Location B, nearest the Plant's discharge, were cooler than those recorded at Locations A and C.

Increased bottom water temperatures as a probable result of Plant operation were detected only on 17 November, when ambient lake temperatures may have been cold enough to result in a sinking thermal plume. The wide temperature differential between gill net locations on 21 July is not attributed to KNPP operation as thermal influence from the Plant's discharge has not been detected in bottom waters as distant from the Plant as Location C (NALCO Environmental Sciences 1976).

Shoreline surface water temperatures recorded at minnow seine locations ranged from 3.3 C on 15 November to 20.6 C on 24 August (Table 9.1). Variations in water temperatures between

Table 9.1. Water temperatures (°C) recorded at fish sampling locations in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

	Water Temperatures at Gill Net Locations							
Location	April 28	May 19	June 16	July 21	August 25	September 23	October 20	November 17
A	5.6	7.9	6.2	7.9	13.9	14.5	9.2	5.2
B	5.9	7.8	5.9	7.5	13.3	14.1	9.4	4.2
C	*[a]	7.9	6.2	11.0	13.4	14.1	9.4	2.6

	Water Temperatures at Minnow Seine Locations							
Location	April 27	May 18	June 14	July 19	August 24	September 20	October 18	November 15
5	6.1	10.6	11.7	*	20.0	14.4	8.3	3.3
9	6.1	10.0	11.1	*	20.0	14.4	8.3	3.3
19	6.7	10.6	11.1	*	20.6	15.5	10.0	3.9

[a] No data - equipment malfunction.

seining locations on a given sampling date were similar to those observed at gill net locations. Temperature variations usually did not exceed 0.6 C, except on 20 September and 18 October when temperatures at Location 19 were 1.1 C and 1.7 C warmer, respectively, than those recorded at Locations 5 and 9. At no time during this study were shoreline water temperatures at Location 9, adjacent to the Plant's discharge, warmer than those recorded at Locations 5 or 19.

As was the case in the 1975 study (LaJeone 1976), operation of KNPP had a negligible influence on fish sampling locations during the 1976 study.

B. Fish Collections

1. General

Twenty-one species of fish and one hydrid were collected in Lake Michigan near KNPP during 1976 (Table 9.2). A total of 5952 individual fish was collected, with gill net catches accounting for 80.5% (4789 fish) of the total catch and minnow seining providing 19.5% (1163 fish) of the total catch (Table 9.3). Fish collected in egg and larvae samples are not included in this general discussion.

Of the 22 fishes collected, 11 species individually comprised 1.0% or more of the total catch and, collectively, these 11 species comprised 99.4% of the total catch. Major species collected in 1976, in order of rank, were alewife, rainbow smelt, lake chub, lake trout, yellow perch, white sucker, longnose dace, slimy sculpin, brown trout, chinook salmon and longnose sucker. In

Table 9.2. Checklist of fish species collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Species[a]	
Common Name	Scientific Name
Alewife	Alosa pseudoharengus
Lake whitefish	Coregonus clupeaformis
Round whitefish	Prosopium cylindraceum
Coho salmon	Oncorhynchus kisutch
Chinook salmon	Oncorhynchus tshawytscha
Rainbow trout	Salmo gairdneri
Brown trout	Salmo trutta
Brook trout	Salvelinus fontinalis
Lake trout	Salvelinus namaycush
Tiger trout (hybrid)	(S. fontinalis x S. trutta)
Rainbow smelt	Osmerus mordax
Lake chub	Couesius plumbeus
Carp	Cyprinus carpio
Fathead minnow	Pimephales promelas
Longnose dace	Rhinichthys cataractae
Creek chub	Semotilus atromaculatus
Longnose sucker	Catostomus catostomus
White sucker	Catostomus commersoni
Shorthead redhorse	Moxostoma macrolepidotum
Ninespine stickleback	Pungitius pungitius
Yellow perch	Perca flavescens
Slimy sculpin	Cottus cognatus

[a] Species names according to Bailey (1970).

previous studies (LaJeone 1974, 1975, 1976) only nine of these species were considered major constituents of the annual total catch; however, slimy sculpin and chinook salmon were collected in sufficient numbers during this study to be classified as major species. The inclusion of these two species is not viewed as an indication of increased real abundance in the study area but merely increased relative abundance in the total catch.

Seventeen species of fish were collected by gill net (Table 9.3). The largest portion of the catch was taken at Location C (43.7%), with 31.4% taken at Location A and 24.8% taken at Location B. Major constituents of the gill net collections (1% or more) were alewife, rainbow smelt, lake trout, yellow perch, white sucker, lake chub, brown trout, chinook salmon and longnose sucker. Collectively these nine species comprised 99.5% of the total gill net catch. Species collected only by gill net were lake trout, yellow perch, white sucker, lake whitefish, round whitefish, coho salmon, shorthead redhorse, carp, brook trout and tiger trout.

Twelve species were collected by minnow seine (Table 9.3). Of the total number of fish collected by seine, 81.2% (944 fish) were taken at Location 5, 15.3% (178 Fish) were taken at Location 19, and 3.5% (41 fish) were taken at Location 9. The paucity of fish collected at Location 9, nearest the KNPP discharge, is attributed to a fine sand substrate and very shallow water, as compared to primarily gravel and cobble substrate with deeper water at Locations 5 and 19. Major species in seine collections were lake chub, longnose dace, slimy sculpin, alewife and rainbow smelt.

Table 9.3. Catch totals of individual fish species collected by gill net and minnow seine in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

	Number of Fish/Gill Net Location					Number of Fish/Minnow Seine Location						
	Location					Location						
Species	A	B	C	Total	Percent of Catch	5	9	19	Total	Percent of Catch	Total Catch	Percent of Total Catch
Alewife	674	723	1219	2616	54.6	42	11	3	56	4.8	2672	44.9
Rainbow smelt	437	185	474	1096	22.9	29	13	4	46	4.0	1142	19.2
Lake chub	42	36	19	97	2.0	739	1	58	798	68.6	895	15.0
Lake trout	136	122	174	432	9.0	0	0	0	0	-	432	7.3
Yellow perch	59	29	79	167	3.5	0	0	0	0	-	167	2.8
White sucker	86	20	57	163	3.4	0	0	0	0	-	163	2.7
Longnose dace	0	0	0	0	-	50	5	73	128	11.0	128	2.2
Slimy sculpin	0	0	0	0	-	76	0	36	112	9.6	112	1.9
Brown trout	26	35	14	75	1.6	0	0	2	2	Tr	77	1.3
Chinook salmon	26	23	12	61	1.3	1	8	0	9	Tr	70	1.2
Longnose sucker	10	6	40	56	1.2	0	1	0	1	Tr	57	1.0
Rainbow trout	1	2	1	4	Tr[a]	0	2	1	3	Tr	7	Tr
Lake whitefish	3	1	3	7	Tr	0	0	0	0	-	7	Tr
Round whitefish	0	4	1	5	Tr	0	0	0	0	-	5	Tr
Creek chub	0	0	0	0	-	5	0	0	5	Tr	5	Tr
Coho salmon	2	2	0	4	Tr	0	0	0	0	-	4	Tr
Shorthead redhorse	2	0	0	2	Tr	0	0	0	0	-	2	Tr
Carp	2	0	0	2	Tr	0	0	0	0	-	2	Tr
Fathead minnow	0	0	0	0	-	1	0	1	2	Tr	2	Tr
Brook trout	0	1	0	1	Tr	0	0	0	0	-	1	Tr
Tiger trout	0	1	0	1	Tr	0	0	0	0	-	1	Tr
Ninespine stickleback	0	0	0	0	-	1	0	0	1	Tr	1	Tr
Total	1505	1190	2094	4789		944	41	178	1163		5952	
Percent of Catch/ Sampling Method	31.4	24.8	43.7	100.0		81.2	3.5	15.3	100.0			

[a] Trace - less than 1.0%.

Collectively these five species comprised 98.0% of the total seine catch. Species collected only by seine were longnose dace, slimy sculpin, creek chub, fathead minnow and ninespine stickleback.

One specimen of the hydrid tiger trout was the only fish collected for the first time in 1976. None of the fish species collected in 1976 occur in the list of threatened animals of Wisconsin (Wisconsin Department of Natural Resources 1973).

2. Discussion of Species

a. Alewife

Alewife was the most abundant species in the 1976 fish collections. A total of 2672 was collected, comprising 44.9% of the total catch (Table 9.3). A total of 2616 (54.6% of the gill net catch) was taken by gill net while 56 (4.8% of the seine catch) were collected by minnow seine. Alewives were collected each month of sampling, but large catches were made only in May, June and July (Figure 9.2).

Gill net catches consisted almost entirely of adult alewives while seine collections consisted of both adult and juvenile fish. Comparison of length frequency data compiled in this study (Table 9.4) with data reported by Norden (1967) indicates that all age groups of alewives occurred within the study area at various times. Alewives ranged in length from 35 to 215 millimeters. Adults, ranging in length from 140 to 215 millimeters, were collected during each month but yearlings (60-109 millimeters) were collected only in May and June, and young-of-year (35-73 millimeters) were collected only in August and October.

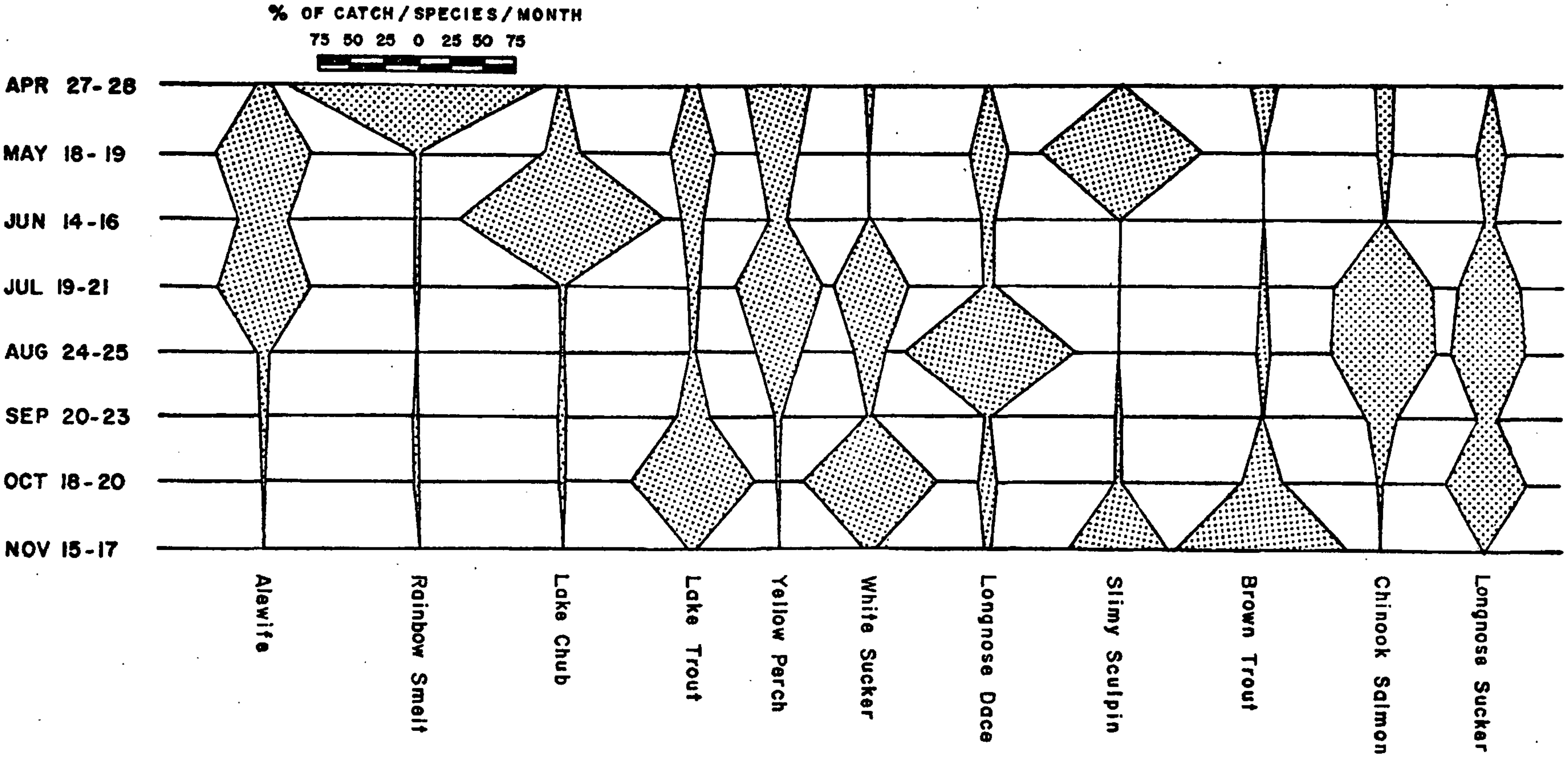

Figure 9.2. Seasonal abundance of major fish species collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Table 9.4. Length frequency distribution of alewife collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Size Class (mm)	Number of Fish/Size Class/Month								Total	Mean Weight (g)	Mean Condition (K)
	Month										
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov			
30-39	0	0	0	0	1	0	0	0	1	*[a]	*
40-49	0	0	0	0	0	0	0	0	0	-	-
50-59	0	0	0	0	0	0	0	0	0	-	-
60-69	0	1	1	0	0	0	0	0	2	1.3	0.39
70-79	0	3	5	0	0	0	1	0	9	2.2	0.50
80-89	0	1	1	0	0	0	0	0	2	2.5	0.45
90-99	0	0	1	0	0	0	0	0	1	5.0	0.64
100-109	0	0	1	0	0	0	0	0	1	8.0	0.73
110-119	0	0	0	0	0	0	0	0	0	-	-
120-129	0	0	0	0	0	0	0	0	0	-	-
130-139	0	0	0	0	0	0	0	0	0	-	-
140-149	0	1	1	0	0	1	0	0	3	25.0	0.85
150-159	0	10	7	10	1	1	1	0	30	28.5	0.79
160-169	2	29	19	15	0	4	3	1	73	33.5	0.77
170-179	22	30	11	18	11	9	5	0	106	36.6	0.70
180-189	26	21	30	19	17	6	5	0	124	40.2	0.66
190-199	9	10	7	11	2	3	0	0	42	46.5	0.66
200-209	7	7	0	2	2	2	0	0	20	53.1	0.65
210-219	1	1	1	0	0	0	0	0	3	73.3	0.75
Total	67	114	85	75	34	26	15	1	417		

[a] Not determined.

No pattern of spatial distribution within the study area was detected. Too few alewives were collected by seine to depict any distributional pattern (Figure 9.3), and the locations of greatest abundance in monthly gill net collections varied consideraly from month to month (Figure 9.4). Alewives are attracted to thermal effluents of nuclear power plants at certain times of year (Spigarell 1975) and it is believed that similar attraction does occur at KNPP; however, such attraction has not been detected in this study program.

Adult alewives were collected in spawning condition in June and July, and eggs were collected at all pump sampling locations on 21 July (Table 9.5). The largest number of eggs was collected at Location 6, where eggs were 12 times more numerous than the second largest collection at Location 12. No larval alewives were collected but many of the eggs in the July samples contained well developed embryos and indicate that alewives had spawned successfully within the study area again in 1976.

b. Rainbow smelt

Rainbow smelt was the second most abundant species collected in 1976. A total of 1142 was collected, comprising 19.2% of the total catch (Table 9.3). Smelt comprised 22.9% (1069 fish) of the gill net catch and 4.0% (46 fish) of the seine catch. Smelt were collected each month of sampling except for August and November, and peak abundance occurred in April (Figure 9.2). April collections resulted in the only large catch of smelt (97.4%) for the entire study period and, following April, monthly catches never exceeded 13 individuals.

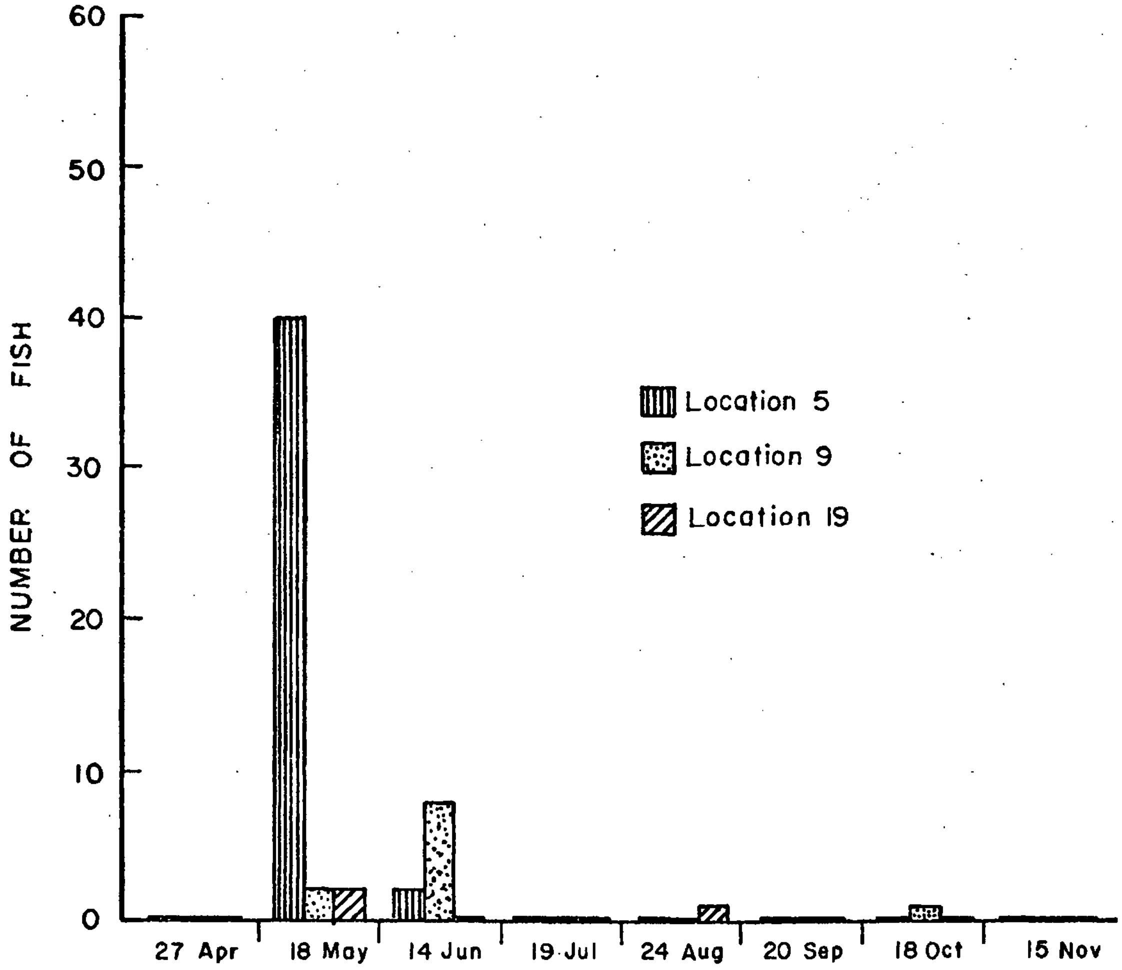

Figure 9.3. Distribution of alewife collected by minnow seine in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

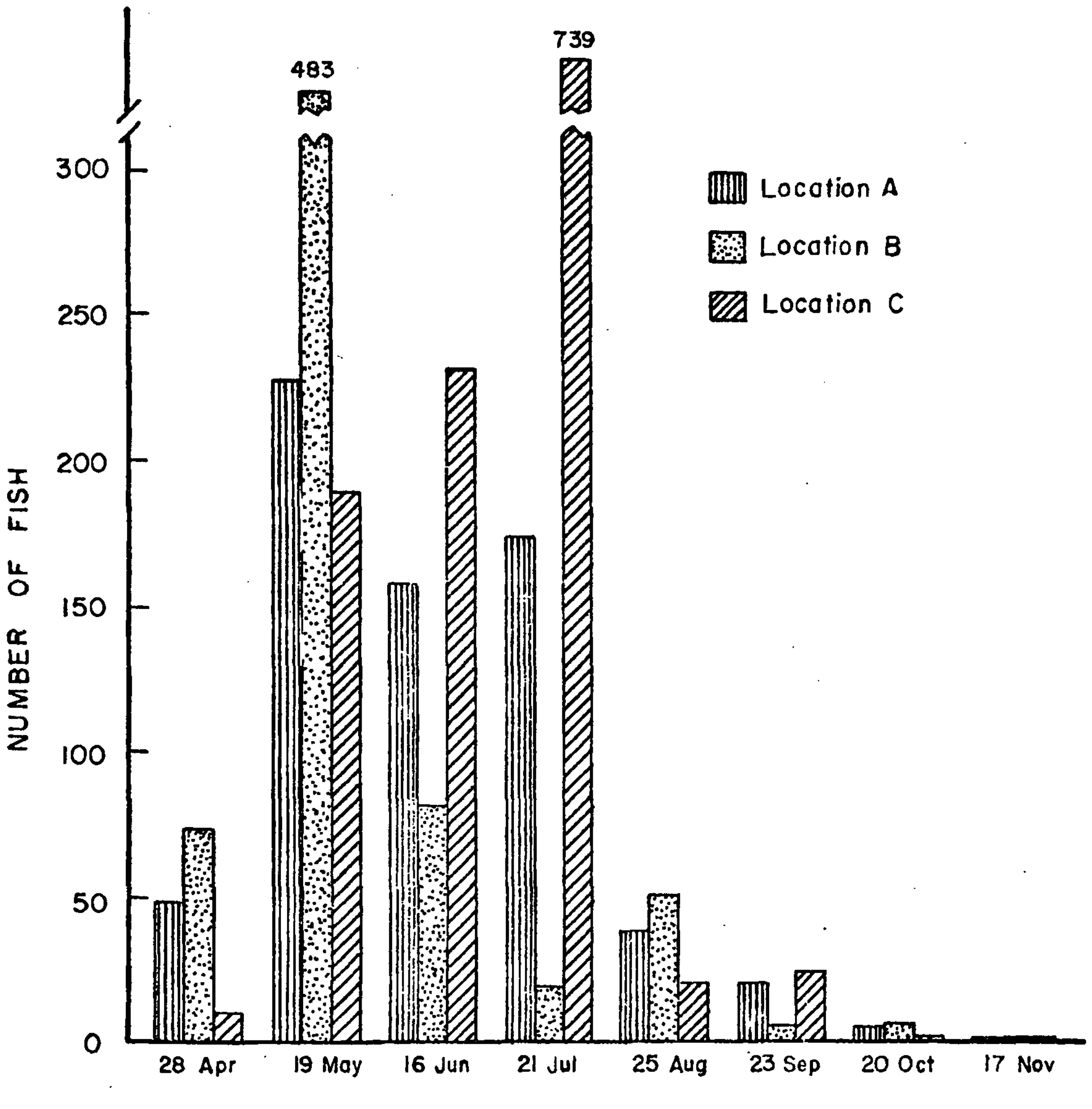

Figure 9.4. Distribution of alewife collected by gill net in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Table 9.5. Early life stages of fish collected by pump in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Date	Sampling Location	Sampling Depth (ft)	Species	Life Stage	Number	Mean[a] Size (mm)
April 27	6	10	Rainbow smelt	egg	9	1.00
	7	20	Slimy sculpin Rainbow smelt	juvenile egg	1 1	49.00 1.00
	11	10	Rainbow smelt	egg	56	0.96
	12	20	Rainbow smelt	egg	1	0.95
	20	10	Rainbow smelt	egg	1	0.96
May 19	6	10	Rainbow smelt	egg	1	1.15
	7	20	Rainbow smelt	egg	1	1.10
	11	10	Rainbow smelt	egg	79	1.07
	20	10	Rainbow smelt	egg	10	1.06
	21	20	Rainbow smelt	egg	1	1.10
July 21	6	10	Slimy sculpin Alewife	juvenile egg	2 2257	14.00 0.99
	7	20	Slimy sculpin Alewife	juvenile egg	16 32	11.20 0.99
	11	10	Alewife	egg	90	1.00
	12	20	Slimy sculpin Alewife	juvenile egg	3 187	14.70 0.99
	20	10	Alewife	egg	13	0.99
	21	20	Alewife	egg	127	0.98
September 24	7	20	Slimy sculpin	juvenile	1	25.00
November 17	7	20	Slimy sculpin	juvenile	1	38.00

[a] Egg measurements are by diameter. All other life stages are total length.

Both gill net and seine collections consisted primarily of adult smelt. Smelt ranged in length from 52 to 280 millimeters (Table 9.6). Smelt were considered mature adults at lengths of 130 millimeters and larger and, of the 1142 fish collected, only 13 individuals fell below that length. Juvenile smelt, probably yearlings, were collected only in May and June while only one specimen considered young-of-year was collected in October.

Catch data for smelt did not indicate any pattern of spatial distribution within the study area. Too few were collected by seine (Figure 9.5) and, with the exception of April collections, too few were also taken by gill net (Figure 9.6).

Adult smelt examined in April were in spawning condition. Smelt eggs were collected in pump samples at five of th six locations in both April and May, with the largest numbers occur ing at Location 11 for both months (Table 9.5). It appears that smelt did spawn successfully along shore throughout the study area.

c. <u>Lake Chub</u>

Lake chub was the third most abundant species, and the most common minnow (Cyprinidae) collected in 1976. A total of 895 was collected, comprising 15.0% of the total catch (Table 9.3). Lake chubs accounted for only 2.0% (97 fish) of the gill net catch but constituted 68.6% (798 fish) of the seine catch. Peak abundance occurred in June, though small numbers were collected each month of sampling (Figure 9.2).

Lake chubs ranged in length from 43 to 195 millimeters, though the majority of the catch consisted of larger, adult

Table 9.6. Length frequency distribution of rainbow smelt collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Size Class (mm)	Number of Fish/Size Class/Month Month Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total	Mean Weight (g)	Mean Condition (K)
50-59	0	4	0	0	0	0	1	0	5	1.0	0.58
60-69	0	4	0	0	0	0	0	0	4	1.5	0.54
70-79	0	1	2	0	0	0	0	0	3	2.0	0.49
80-89	0	1	0	0	0	0	0	0	1	3.0	0.58
90-99	0	0	0	0	0	0	0	0	0	-	-
100-109	0	0	0	0	0	0	0	0	0	-	-
110-119	0	0	0	0	0	0	0	0	0	-	-
120-129	0	0	0	0	0	0	0	0	0	-	-
130-139	3	0	0	0	0	0	0	0	3	14.3	0.62
140-149	6	0	0	0	0	0	0	0	6	18.0	0.64
150-159	2	1	0	2	0	0	0	0	5	19.0	0.56
160-169	8	0	0	2	0	0	0	0	10	27.6	0.64
170-179	8	0	0	0	0	0	0	0	8	34.6	0.67
180-189	11	0	0	0	0	0	0	0	11	39.8	0.65
190-199	14	0	1	0	0	0	0	0	15	46.9	0.65
200-209	12	0	0	0	0	0	0	0	12	49.2	0.59
210-219	7	2	1	0	0	1	0	0	11	58.2	0.59
220-229	13	0	0	0	0	1	0	0	14	62.1	0.56
230-239	6	0	0	2	0	0	0	0	8	80.0	0.62
240-249	0	0	1	3	0	0	0	0	4	85.0	0.58
250-259	1	0	0	0	0	0	0	0	1	115.0	0.69
260-269	0	0	0	0	0	0	0	0	0	-	-
270-279	0	0	0	0	0	0	0	0	0	-	-
280-289	1	0	0	0	0	0	0	0	1	145.0	0.66
Total	92	13	5	9	0	2	1	0	122		

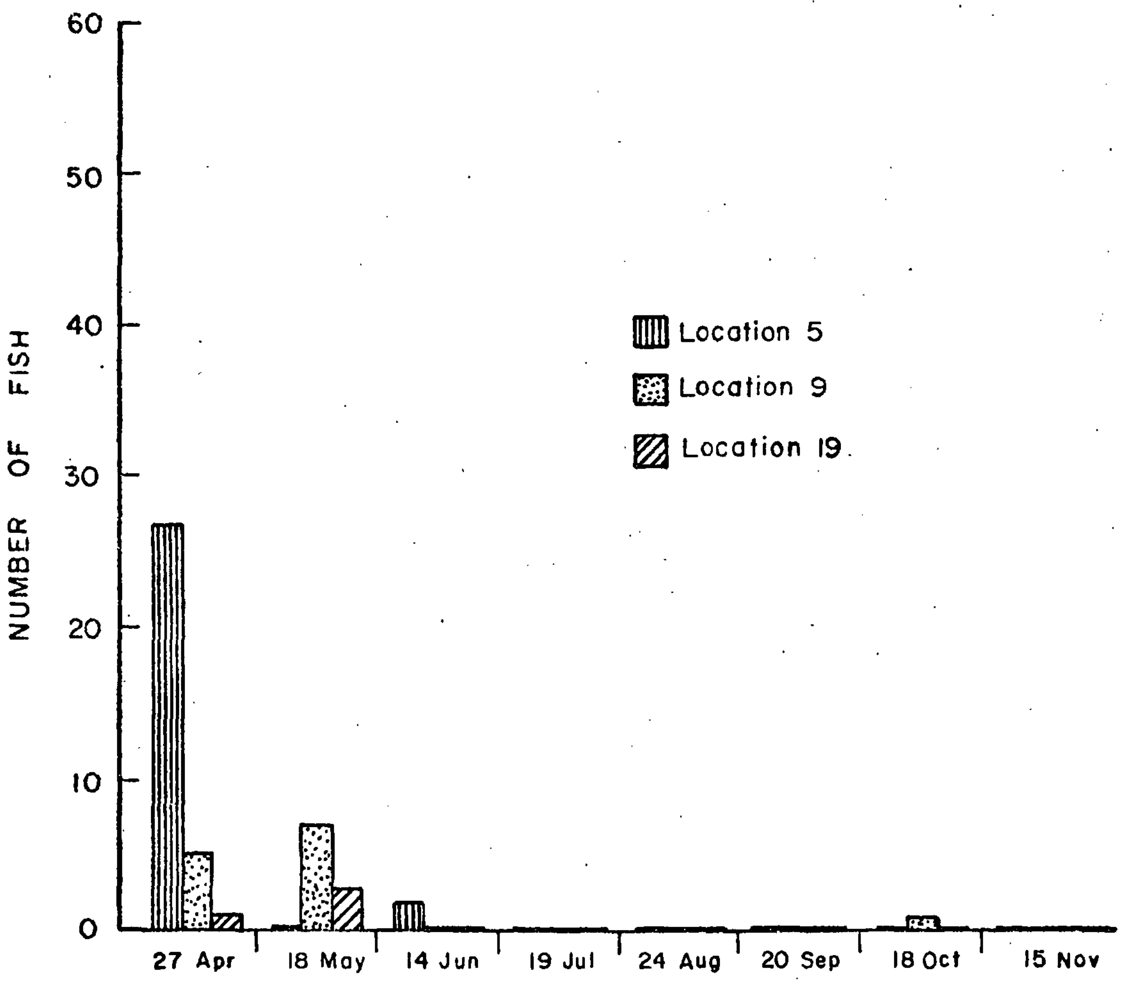

Figure 9.5. Distribution of rainbow smelt collected by minnow seine in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

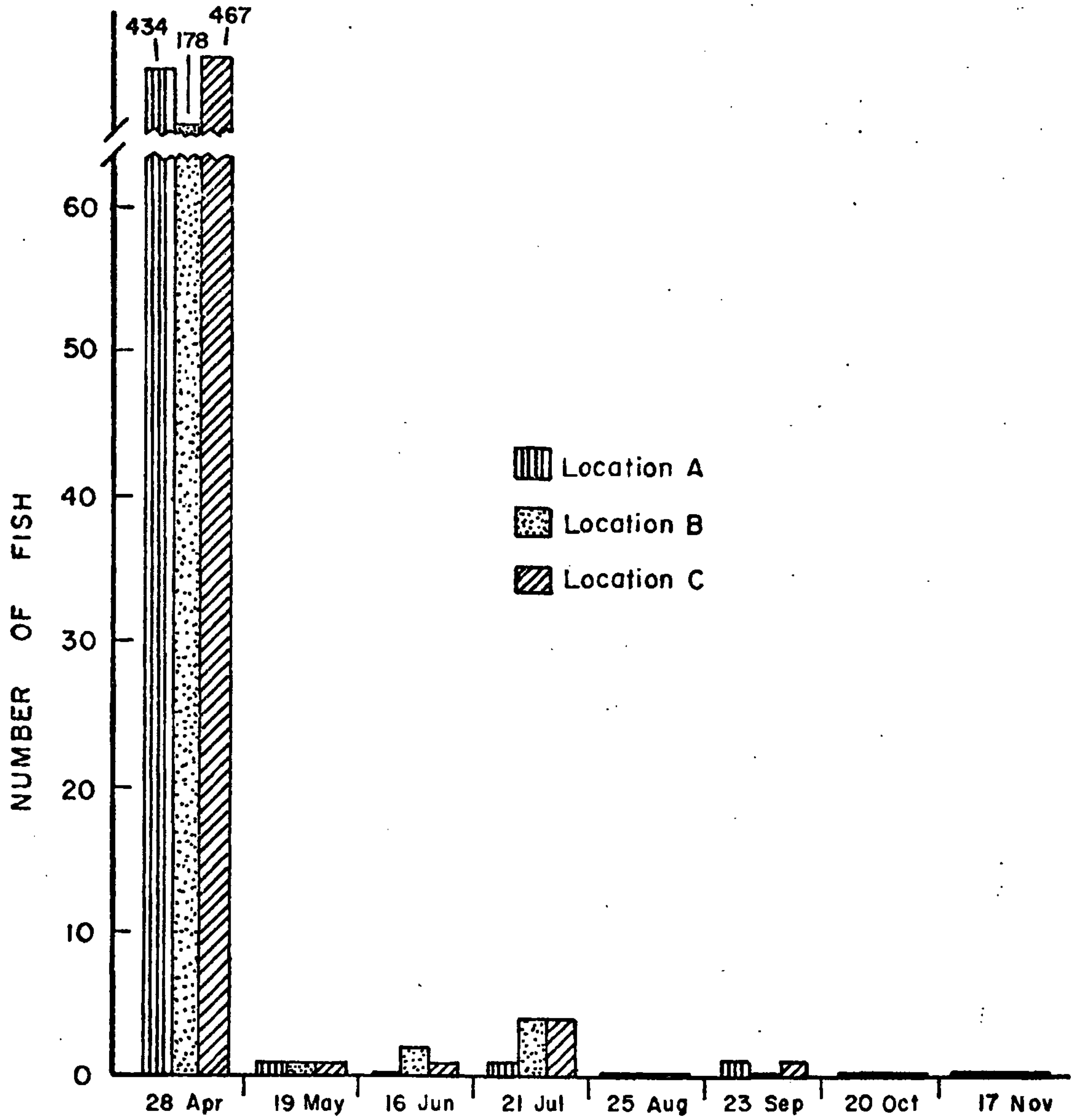

Figure 9.6. Distribution of rainbow smelt collected by gill net in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

fish ranging from 120 to 195 millimeters (Table 9.7). Juvenile lake chubs were collected only in May and August. There appears to be differential growth between the sexes as females were usually much larger than males. Seine collections took all sizes of fish and males were equally as abundant as females; however, gill net catches consisted almost entirely of large females.

The distribution of lake chubs along shore within the study area may be attributed to spawning requirements of the species. Adults collected in May were in ripe gonadal condition and substantial numbers were taken in seine hauls at Locations 5 and 19 while only one specimen was taken at Location 9 (Figure 9.7). This is an indication that gravel and cobble substrates at Locations 5 and 19 are preferred to the fine sand substrate at Location 9. The largest catch of lake chubs (692 fish) was taken by seine at Location 5 in June. Adults in that collection were in ripe and running gonadal condition and were apparently trying to enter the intermittent stream at Location 5 which was flowing into the lake at a temperature of 20 C. No distribution pattern was discernable from gill net collections (Figure 9.8). Lake chubs may spawn along suitable shorelines within the study area but no eggs, larvae or young-of-year were collected. It is believed that this species does spawn successfully in tributary streams in the vicinity of KNPP.

Lake chubs are considered a forage species but were not identified from the stomach contents of species examined. Also roughly 50% of the specimens examined were infected with black spot (Uvulifer sp. or Neascus sp.).

Table 9.7. Length frequency distribution of lake chub collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Size Class (mm)	Number of Fish/Size Class/Month								Total	Mean Weight (g)	Mean Condition (K)
	Month										
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov			
40-49	0	2	0	0	0	0	0	0	2	*[a]	*
50-59	0	1	0	0	1	0	0	0	2	*	*
60-69	0	16	0	0	0	0	0	0	16	1.5	0.54
70-79	0	7	0	0	0	0	0	0	7	3.3	0.76
80-89	0	3	0	0	0	0	0	0	3	4.5	0.75
90-99	0	0	0	0	1	0	0	0	1	10.0	1.06
100-109	0	0	0	0	1	0	0	0	1	11.0	1.03
110-119	0	2	1	0	0	1	0	0	4	12.3	0.85
120-129	0	8	2	0	0	0	0	0	10	15.9	0.80
130-139	1	8	4	0	0	0	0	0	13	23.9	0.99
140-149	2	11	6	0	0	0	0	0	19	31.2	1.01
150-159	7	13	12	0	1	0	0	0	33	36.8	0.98
160-169	8	15	8	0	0	1	4	0	36	43.9	1.00
170-179	5	17	13	4	2	12	9	0	62	52.1	0.99
180-189	6	11	9	5	0	4	1	1	37	63.8	1.04
190-199	0	0	1	1	0	1	0	0	3	69.0	0.97
Total	29	114	56	10	6	19	14	1	249		

[a] Not determined.

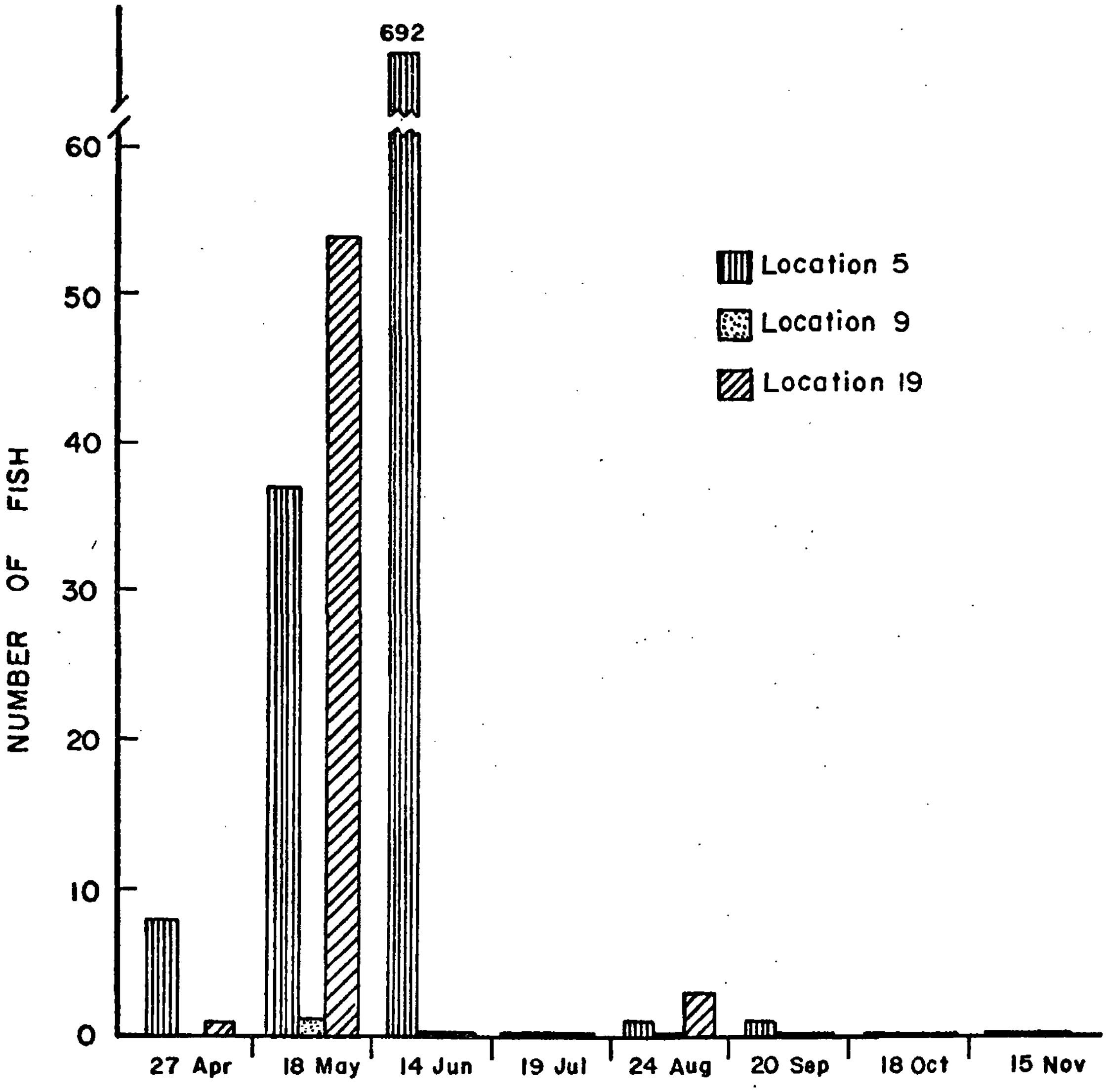

Figure 9.7. Distribution of lake chub collected by minnow seine in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

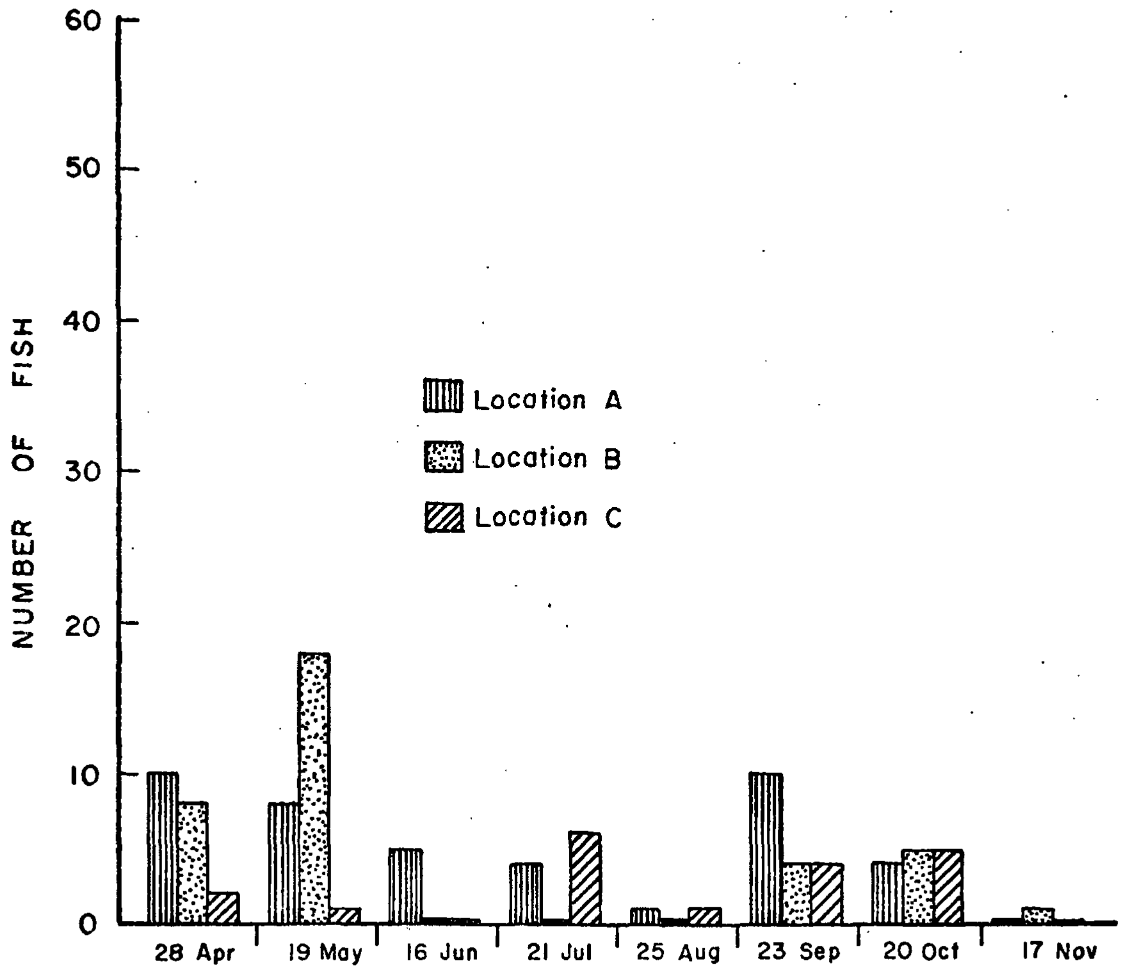

Figure 9.8. Distribution of lake chub collected by gill net in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

d. Lake trout

Lake trout ranked fourth in relative abundance in the 1976 fish collections and was the most abundant salmonid species collected. A total of 432 was collected and all were taken in gill nets (Table 9.3). Lake trout comprised 7.3% of the total catch and 9.0% of the gill net catch. They were collected each month of sampling with peak abundance occurring in October and a lesser peak occurring in May (Figure 9.2). No pattern of spatial distribution within the study area was apparent as lake trout were not taken in consistantly greater numbers at any one sampling location throughout the study period (Figure 9.9).

Large numbers of lake trout are planted annually in Lake Michigan by state and federal agencies, and are marked by fin clips to document year class. Plantings prior to 1970 used differer fin clips to further identify planting locations; however, of late, only a few experimental plantings are given area-specific clips. A list of planting locations and fin clips of lake trout collected in 1976 is given in Table 9.8. The majority of older trout taken in 1976 were planted locally though considerable numbers of fish originated from distant localities. Only 16 lake trout collected in 1976 exhibited unrecognizable or no detectable fin clips.

Lake trout collected in 1976 ranged in age from two to twelve years and ranged in average length per age group from 381 to 845 millimeters (Table 9.9). Age groups II through V comprised the majority of the catch from April through June and again in November. Age groups VI through X were the most abundant from July

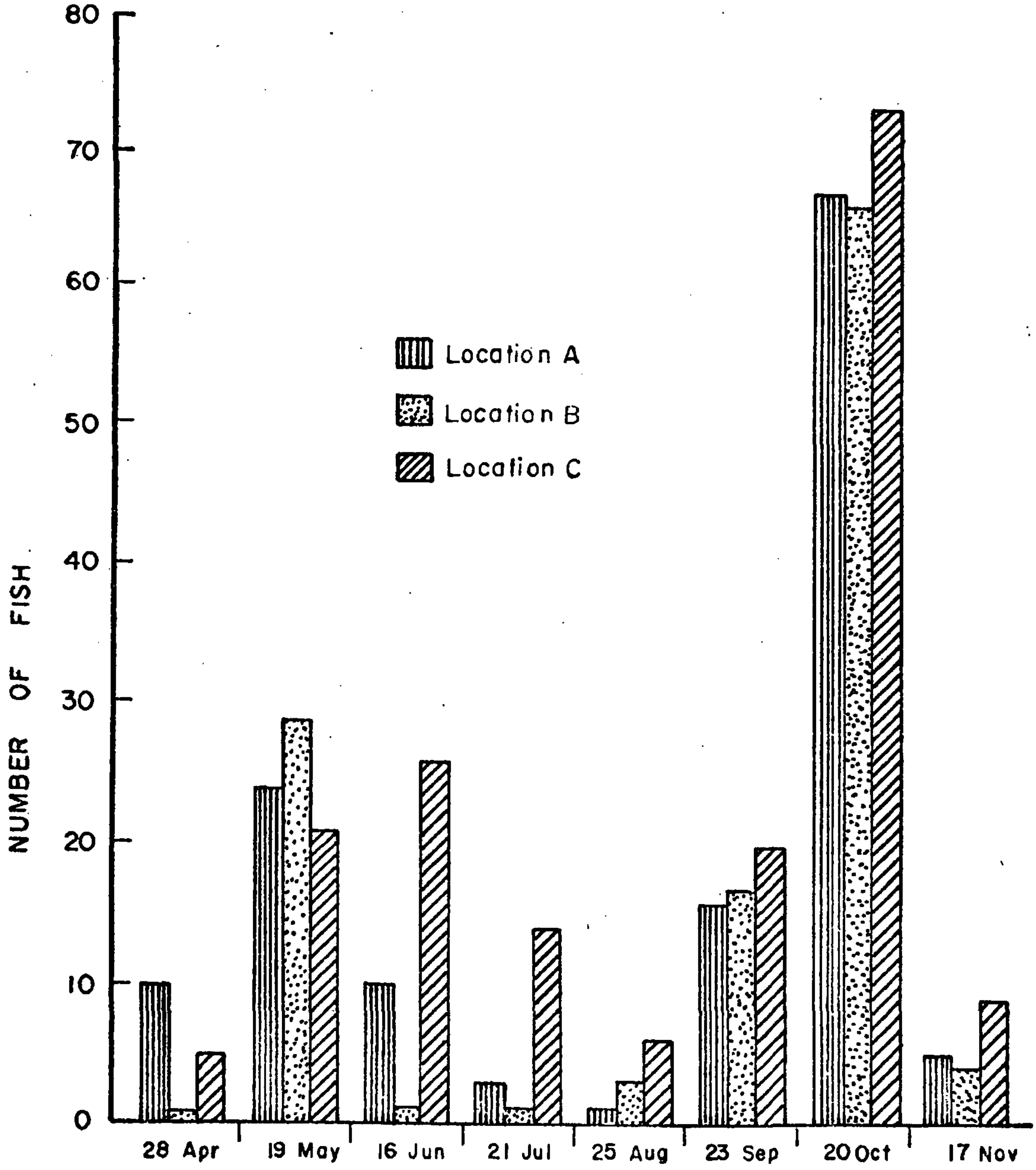

Figure 9.9. Distribution of lake trout collected by gill net in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Table 9.8. Planting locations of fin clipped lake trout collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Year Class	Fin Clip	Planting Location	Total Number
1964	Ad	Kewaunee, Door Peninsula	1
1966	AdLV	Kewaunee, Sand Bay, Sturgeon Bay	28
	AdRV	Great Lakes Naval Dock, Bethlehem Steel Pier	28
1967	LV	Kewaunee, Algoma	38
	Ad	Great Lakes Naval Dock, Bethlehem Steel Pier, New Buffalo, Port Sheldon	6
	D	Sheboygan, Port Washington	2
1968	RP	Kewaunee, Manitowoc	40
	DLV	Sturgeon Bay, Green Bay	12
	DRV	Milwaukee Reef	3
	LP	Michigan Waters	2
1969	AdRV	Lake Wide	82
1970	LV	Lake Wide	45
1971	RV	Lake Wide	27
1972	Ad	Lake Wide	64
	DRP	Kewaunee, Sheboygan	6
	DLP	Kewaunee, Sheboygan	2
1973	D	Sheboygan, Door Peninsula	6
	AdRV	Lake Wide	4
1974	AdLV	Kewaunee	20
No Clip and Unrecognized Clip			16

Table 9.9. Age group distribution and mean lengths, weights and condition factors of lake trout collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Age Group[a]	Number of Fish/Age Group/Month									Mean Total Length (mm)	Mean Weight (g)	Mean Condition (K)
	Month											
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total			
II	0	3	1	3	0	1	0	12	20	381.0	581.8(14)[b]	1.00
III	0	6	3	0	0	0	0	1	10	448.5	1140.0(4)	0.99
IV	5	51	11	1	0	0	4	0	72	503.3	1301.8(39)	1.04
V	4	6	8	1	0	0	5	3	27	597.0	2144.3(14)	1.06
VI	1	1	2	2	1	8	30	0	45	677.2	3050.0(13)	0.98
VII	4	3	7	6	3	7	52	0	82	710.6	3709.5(21)	1.02
VIII	1	3	2	1	2	10	37	1	57	739.9	4033.3(12)	1.07
IX	0	0	0	2	2	12	30	0	46	755.8	4332.1(14)	1.05
X	0	1	1	2	0	13	38	1	56	778.0	4756.3(16)	1.06
XII	0	0	0	0	1	0	0	0	1	845.0	*[c]	*
No Clip and Unrecognized Clip	1	0	2	0	1	2	10	0	16	702.2	3430.0(7)	1.01

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[a] No age group XI fish collected in 1976.
[b] Number of fish from which weight and condition data were calculated.
[c] Not determined, fish tagged and returned to lake.

through October, reaching peak abundance in October.

Age groups II through IV were sexually immature whil the majority of fish in age groups V through XII were mature adults. From April to July juvenile lake trout were fairly common in the catch but from August to October mature adults dominated the catch. Adults were in ripe gonadal condition in September and by October about 50% of the adults collected were ripe and running. Lake trou probably did spawn within the study area in late October or early November but no evidence of successful reproduction was found.

Scarring and wounding of lake trout by sea lamprey was much in evidence again in 1976 but was comparable to rates reported in 1975 (Tabe 9.10; LaJeone 1976). Frequency of lamprey scar ring was highest in older fish, decreasing in younger age groups wit no evidence of lamprey scarring or wounding in fish younger than ag group V. Fresh lamprey wounds were also observed but the frequency of wounding was less than 10% of the overall scarring rate.

Results of analyses of lake trout stomachs found alewife and smelt as the principal constituents of their diet though sculpin were also occasionally consumed (Table 9.11).

e. Yellow perch

Yellow perch ranked fifth in abundance in the 1976 fish collections. A total of 167 was collected by gill net, compri ing 3.5% of the gill net catch and 2.8% of the total catch (Table 9.3). Yellow perch were collected each month of sampling with peak abundance occurring in July (Figure 9.2). No notably large catches were taken in any one month and, following August, only seven

Table 9.10. Summary of sea lamprey scars and wounds observed on lake trout collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Age Group	Number of Fish Examined	Number Scarred	Percent of Scarring	Number Wounded	Percent of Wounding
II	20	0	0	0	0
III	10	0	0	0	0
IV	72	0	0	0	0
V	27	2	7.4	2	7.4
VI	45	16	35.6	0	0
VII	82	43	52.4	2	2.4
VIII	57	40	70.2	2	3.5
IX	46	33	71.7	3	6.5
X	56	43	76.8	5	8.9
XII	1	1	100.0	0	0
Total	416	178	42.8	14	3.4

Table 9.11. Summary of stomach analyses conducted on various fish species collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Species	Number of Stomachs With Food	Number of Empty Stomachs	Contents	Number	Percent Frequency Occurrence	Volume (ml)	Percent Total Volume
Lake trout	38	30	Alewife	81	71.1	507.0	64.8
			Rainbow smelt	22	28.9	253.0	32.4
			Sculpin	8	10.5	15.0	1.9
			UFR[a]	2	5.3	7.0	Tr[b]
Brown trout	28	5	Alewife	110	64.3	439.0	54.5
			Sculpin	42	25.0	103.0	12.8
			Rainbow smelt	11	14.3	193.0	24.0
			UFR	3	10.7	46.0	5.7
			Gizzard shad	1	3.6	25.0	3.1
Rainbow trout	2	0	Alewife	2	50.0	3.0	50.0
			Sculpin	2	100.0	3.0	50.0
Brook trout	0	1	-	-	-	-	-
Tiger trout	0	1	-	-	-	-	-
Chinook salmon	12	7	Alewife	23	83.3	55.0	87.3
			Longnose dace	1	8.3	7.0	11.1
			UFR	1	8.3	1.0	1.6
Coho salmon	1	0	Alewife	3	100.0	2.0	100.0
Yellow perch	32	25	Sculpin	47	78.1	59.1	76.6
			Alewife	8	18.8	17.6	22.8
			UFR	*[c]	3.1	0.5	Tr

[a] Unidentified fish remains.
[b] Trace-less than 1%.
[c] Not determinable.

individuals were collected. Distribution of yellow perch within the study area was too erratic to depict any location preferences (Figure 9.10.).

Yellow perch ranged in length from 145 to 375 millimeters with fish ranging from 220 to 269 millimeters comprising the majority of the catch (Table 9.12). Ages ranged from one to nine years but age groups VI and VII accounted for 77.4% of all perch for which ages were determined. The wide range of size classes within an age group is attributed to differential growth between sexes, females tending to attain larger sizes than males. Similar observations have been made for perch in eastern Lake Michigan (Brazo et al 1975).

Only two yellow perch aged in 1976 were younger than age group V. In 1975 the dominant age groups were V and VI (LaJeone 1976) and in 1974 age groups IV and V predominated (LaJeone 1975). These same year classes, now age groups VI and VII, were dominant again indicating these were strong year classes. These data also infer that recruitment of younger perch has been poor since production of these year classes.

Yellow perch were in ripe and running gonadal condition in May and fish examined in June were then spent. Limited spawning may have occurred in the study area but no eggs, larvae or young-of-year were collected.

Yellow perch inhabiting the study area fed heavily on sculpin though alewife were also occasionally preyed upon (Table 9.11).

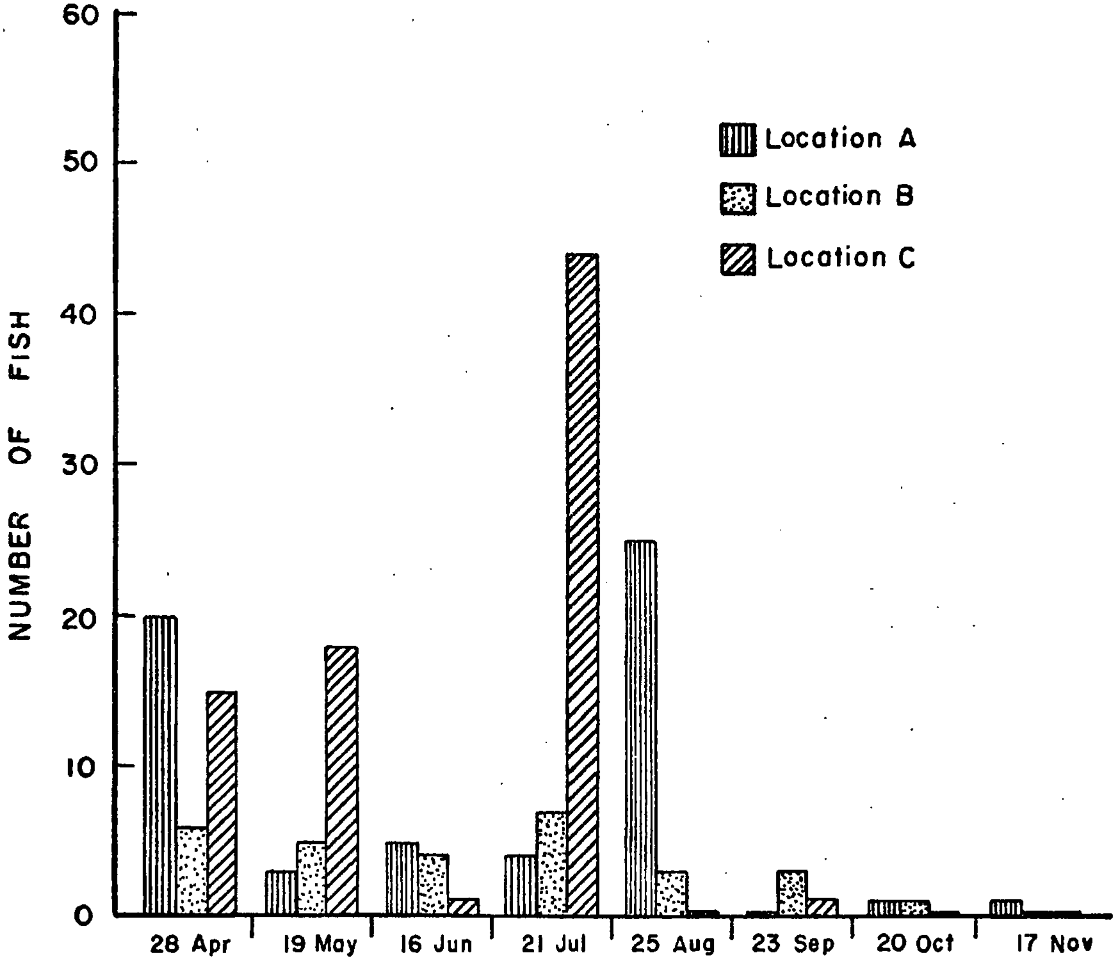

Figure 9.10. Distribution of yellow perch collected by gill net in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Table 9.12. Length frequency and age group distribution of yellow perch collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Size Class (mm)	Number of Fish/Size Class/Age Group									Total	Mean Weight (g)	Mean Condition (K)
	Age Group											
	I	II	III	IV	V	VI	VII	VIII	IX			
140-149	1	0	0	0	0	0	0	0	0	1	35.0	1.14
150-159	0	0	0	0	0	0	0	0	0	0	-	-
160-169	0	0	0	0	0	0	0	0	0	0	-	-
170-179	0	0	0	0	0	0	0	0	0	0	-	-
180-189	0	0	0	0	0	0	0	0	0	0	-	-
190-199	0	0	0	0	0	0	0	0	0	0	-	-
200-209	0	0	0	0	0	0	0	0	0	0	-	-
210-219	0	0	0	1	0	0	0	0	0	1	130.0	1.30
220-229	0	0	0	0	4	7	1	0	0	12	170.4	1.50
230-239	0	0	0	0	0	6	1	0	0	7	170.0	1.35
240-249	0	0	0	0	2	11	4	0	0	17	192.6	1.35
250-259	0	0	0	0	0	5	5	1	0	11	217.3	1.35
260-269	0	0	0	0	0	5	11	0	0	16	255.6	1.40
270-279	0	0	0	0	0	1	1	0	0	2	270.0	1.37
280-289	0	0	0	0	0	1	2	0	0	3	328.3	1.44
290-299	0	0	0	0	0	1	1	0	1	3	405.0	1.57
300-309	0	0	0	0	0	1	0	2	1	4	393.8	1.42
310-319	0	0	0	0	0	0	0	2	0	2	427.5	1.40
320-329	0	0	0	0	0	0	0	1	1	2	567.5	1.65
330-339	0	0	0	0	0	0	1	1	0	2	555.0	1.51
340-349	0	0	0	0	0	0	0	0	0	0	-	-
350-359	0	0	0	0	0	0	0	0	0	0	-	-
360-369	0	0	0	0	0	0	0	0	0	0	-	-
370-379	0	0	0	0	0	0	0	0	1	1	700.0	1.32
Total	1	0	0	1	6	38	27	7	4	84		
Mean Total Length (mm)	145.0.	-	-	215.0	230.8	246.2	260.9	305.7	323.8			
Mean Weight (g)	35.0	-	-	130.0	161.7	212.5	260.4	430.7	503.75			
Mean Condition (K)	1.14	-	-	1.30	1.30	1.39	1.43	1.46	1.46			

f. White sucker

A total of 163 white suckers was collected in 1976, placing this species sixth in abundance for the total catch (Table 9.3). All white suckers were taken in gill nets, comprising 3.4% o the gill net catch and 2.7% of the total catch. White suckers were collected each month except May with peak abundance occurring in October (Figure 9.2). They were taken in appreciable numbers only in July, August and October. Monthly gill net catches did not depi any distribution patterns within the study area (Figure 9.11).

Lengths of white suckers ranged from 275 to 540 millimeters with fish ranging from 360 to 409 millimeters comprising 64.% of the total catch (Table 9.13). The majority of the catch consisted of mature adults with few juveniles and no young-of-year collected. No adults were collected in spawning condition and no eggs or larvae were taken in pump samples. It appears that whit suckers did not spawn in the study area in 1976; however suckers do ascend nearby tributaries in the spring for spawning (Poff and Threinen 1966; Weber et al 1968).

g. Longnose dace

Longnose dace was the only other abundant minnow species collected 1976. A total 128 was collected by seine, comprisin 11.0% of the seine catch and 2.2% of the total catch (Table 9.3). Longnose dace were collected each month of sampling with peak abundance occurring in August (Figure 9.2). They were taken in relatively low numbers except for the August collection and did not show any pronounced pattern of distribution within the study area, other

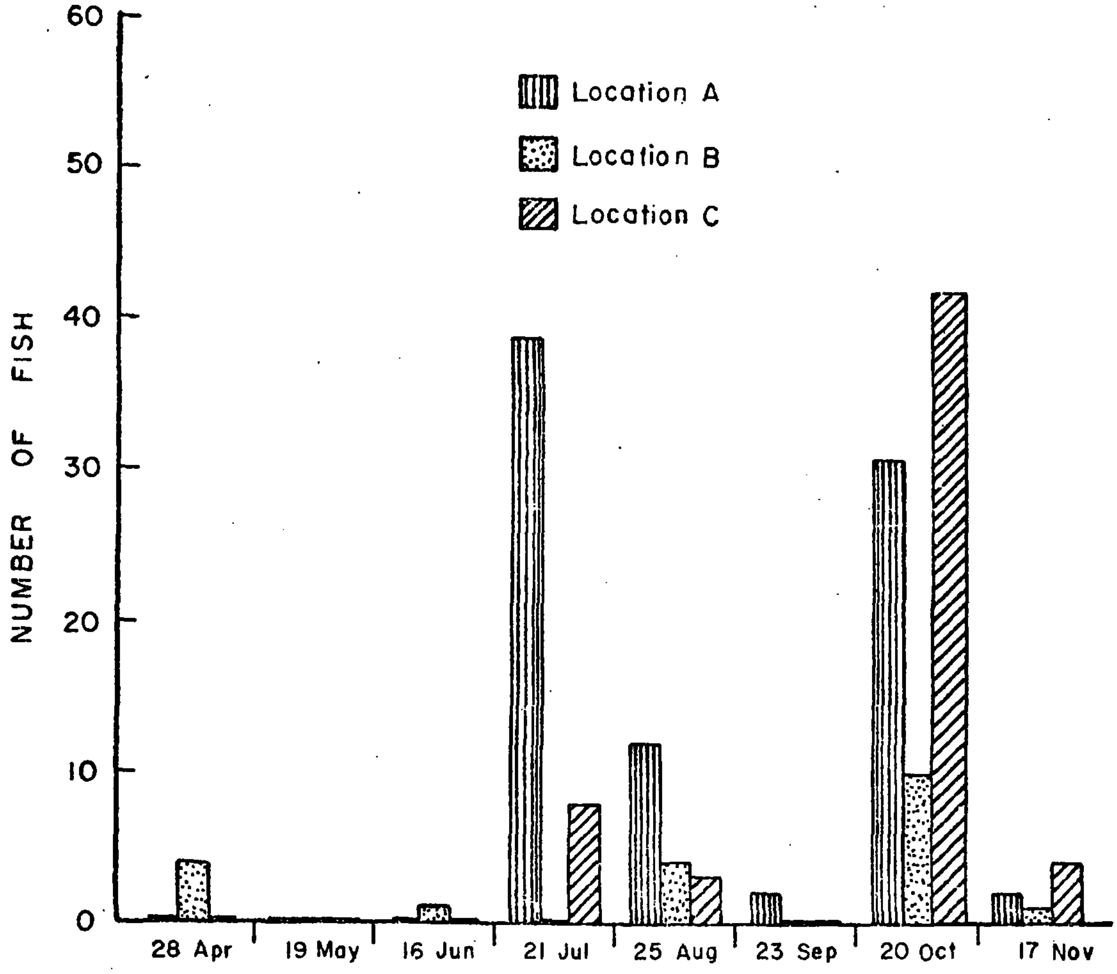

Figure 9.11. Distribution of white sucker collected by gill net in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Table 9.13. Length frequency distribution of white sucker collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Size Class (mm)	Number of Fish/Size Class/Month								Total	Mean Weight (g)	Mean Condition (K)
	Month										
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov			
270-279	0	0	0	1	0	0	0	0	1	245.0	1.17
280-289	1	0	0	1	0	0	0	0	2	252.5	1.15
290-299	0	0	0	0	0	0	1	0	1	300.0	1.16
300-309	0	0	0	0	0	0	0	0	0	-	-
310-319	0	0	0	0	0	0	0	0	0	-	-
320-329	0	0	0	2	0	0	0	0	2	367.5	1.09
330-339	0	0	0	2	0	0	1	0	3	440.0	1.20
340-349	2	0	0	1	0	0	1	0	4	512.5	1.29
350-359	1	0	0	1	0	0	7	0	9	503.9	1.14
360-369	0	0	0	12	3	0	6	0	21	563.8	1.18
370-379	0	0	0	4	4	1	10	1	20	604.3	1.16
380-385	0	0	0	9	1	0	16	0	26	637.9	1.13
390-399	0	0	1	6	3	0	14	0	24	667.9	1.10
400-409	0	0	0	1	4	0	8	1	14	734.6	1.12
410-419	0	0	0	4	1	0	3	0	8	766.3	1.10
420-429	0	0	0	1	1	0	5	0	7	837.1	1.10
430-439	0	0	0	0	0	0	5	0	5	992.0	1.21
440-449	0	0	0	1	1	0	3	0	5	996.0	1.14
450-459	0	0	0	1	1	0	0	0	2	1030.0	1.11
460-469	0	0	0	0	0	1	1	0	2	1025.0	1.04
470-479	0	0	0	0	0	0	0	0	0	-	-
480-489	0	0	0	0	0	0	0	0	0	-	-
490-499	0	0	0	0	0	0	0	0	0	-	-
500-509	0	0	0	0	0	0	0	0	0	-	-
510-519	0	0	0	0	0	0	0	1	1	1750.0	1.28
520-529	0	0	0	0	0	0	2	1	3	1903.3	1.34
530-539	0	0	0	0	0	0	0	2	2	1800.0	1.19
540-549	0	0	0	0	0	0	0	1	1	1900.0	1.20
Total	4	0	1	47	19	2	83	7	163		

than the fact that only five specimens were collected at Location 9 (Figure 9.12).

Longnose dace ranged in length from 22 to 119 millimeters (Table 9.14). Large, adult specimens were most numerous but a considerable number of small juveniles were collected, primarlily in August. Adults were in ripe gonadal condition in June, but the large August catch was not attributed to spawning as adults were in spent condition at that time. No eggs or larvae were collected but some of the small specimens collected in August may have been young-of-year. Longnose dace probably did spawn successfully within the study area, either along shore or in nearby tributaries.

Longnose dace are considered a forage species and were identified from the stomach contents of chinook salmon (Table 9.11). A small number of the specimens examined were infected with black spot.

h. Slimy sculpin

Slimy sculpin ranked eighth in relative abundance of the total catch in 1976 though this species is undoubtedly much more abundant in the area than catch data indicate. A total of 112 was collected by seine, comprising 9.6% of the seine catch and 1.9% of the total catch (Table 9.3). Slimy sculpins were collected in May, September, October and November but appreciable numbers were taken only in May and November (Figure 9.2). Despite the sporadic catches of this species, there appeared to be some decided habitat perferences. No fish were collected at Location 9 while 76 and 36 specimens were collected at Locations 5 and 19, respectively (Figure

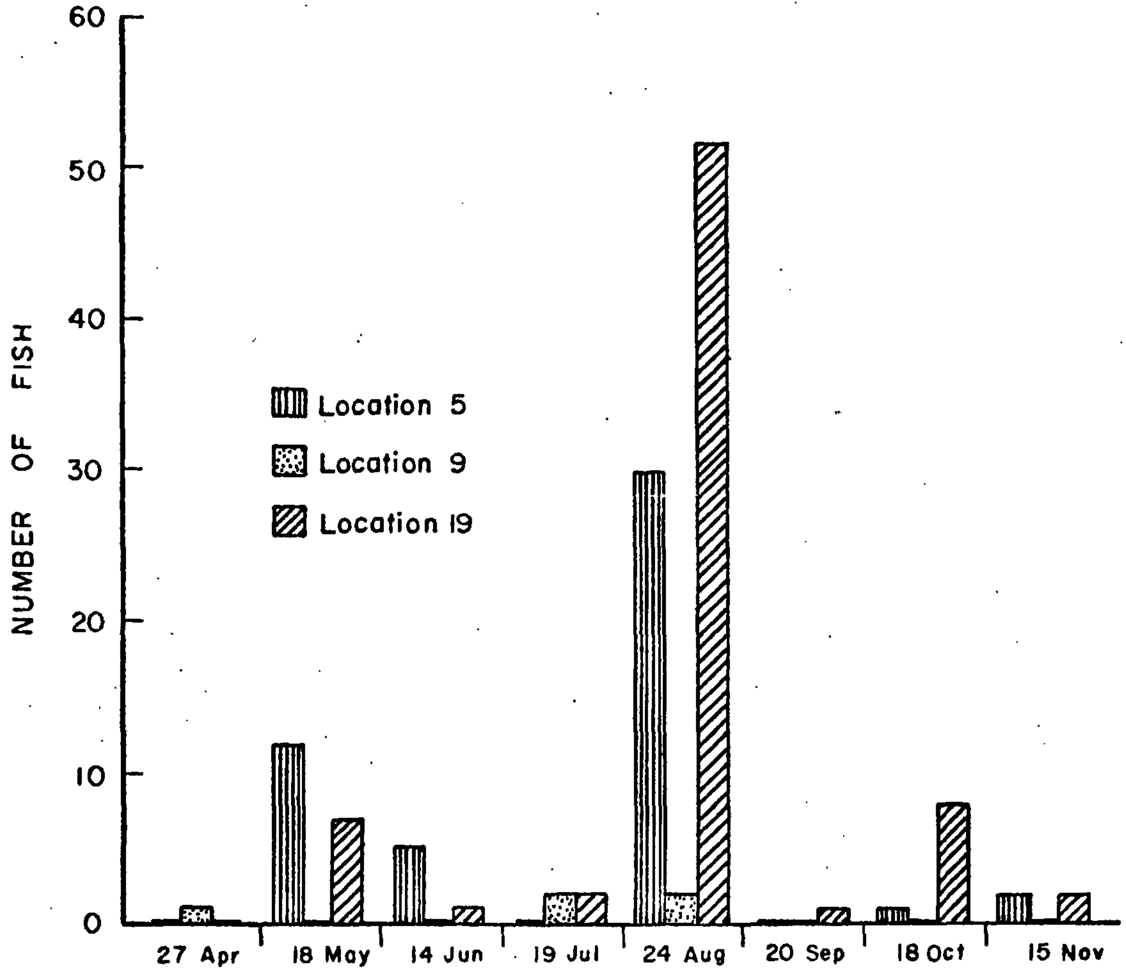

Figure 9.12. Distribution of longnose dace collected by minnow seine in Lake Michigan near the Kewaune Nuclear Power Plant, April through November 19

Table 9.14. Length frequency distribution of longnose dace collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Size Class (mm)	Number of Fish/Size Class/Month								Total	Mean Weight (g)	Mean Condition (K)
	Month										
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov			
20-29	0	0	0	0	5	0	0	0	5	*a	*
30-39	0	1	0	0	15	0	0	2	18	*	*
40-49	0	1	1	1	0	0	6	1	10	*	*
50-59	0	0	0	1	2	0	1	0	4	1.5	0.85
60-69	0	1	0	0	8	0	0	0	9	2.5	0.88
70-79	0	1	0	0	5	1	1	1	9	3.3	0.82
80-89	0	6	2	0	24	0	0	0	32	6.1	1.01
90-99	1	6	2	1	11	0	0	0	21	8.2	1.01
100-109	0	1	1	1	12	0	1	0	16	12.0	1.06
110-119	0	2	0	0	2	0	0	0	4	13.3	0.90
Total	1	19	6	4	84	1	9	4	128		

[a] Not determined.

9.13), indicating that gravel and cobble are preferred to fine sand habitat.

Slimy sculpins collected by seine ranged in length from 27 to 73 millimeters with the majority of the catch consisting of adults ranging from 50 to 69 millimeters (Table 9.15). Adults collected in May were in spent gonadal condition. No eggs or larva were collected but serveral specimens considered young-of-year were found in pump samples collected at Locations 6, 7 and 12 on 21 July (Table 9.5), indicating they had spawned successfully within the study area.

Slimy sculpin are valuable only as forage for larger piscivorous species. They are the primary food of yellow perch in the study area and are important constituents in the diets of lake trout, brown trout and rainbow trout (Table 9.11).

i. <u>Brown trout</u>

Brown trout was the second most commonly collected salmonid species in 1976. A total of 77 was collected and all but two were taken by gill net (Table 9.3). Brown trout comprised 1.6% of the gill net catch and 1.3% of the total catch. They were collected in all months of sampling, except May and June, with peak abundance occurring in November (Figure 9.2). Catches were too sma from April to October to depict any distribution pattern; however, in November brown trout were substantially more abundant at Locatio A and B than at Location C (Figure 9.14). Greater abundance at the locations may be in response to warmer water temeratures possibly due to the Plant's thermal plume.

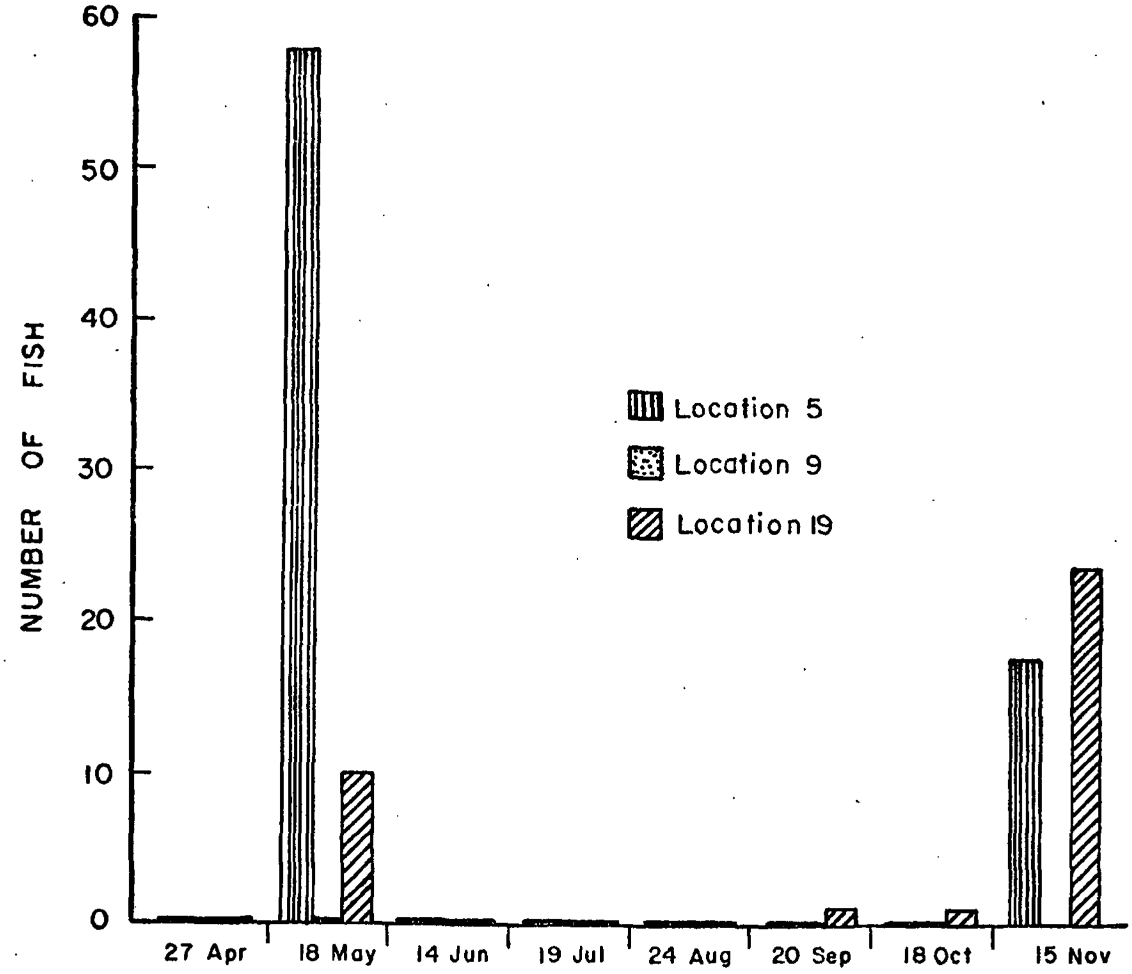

Figure 9.13. Distribution of slimy sculpin collected by minnow seine in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Table 9.15. Length frequency distribution of slimy sculpin collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Size Class (mm)	Number of Fish/Size Class/Month								Total	Mean[a] Weight (g)	Mean Condition (K)
	Month										
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov			
20-29	0	0	0	0	0	0	0	1	1	*[b]	*
30-39	0	4	0	0	0	1	0	5	10	*	*
40-49	0	4	0	0	0	0	1	3	8	*	*
50-59	0	19	0	0	0	0	0	13	32	1.8	1.10
60-69	0	39	0	0	0	0	0	18	57	2.6	1.01
70-79	0	2	0	0	0	0	0	2	4	3.5	0.90
Total	0	68	0	0	0	1	1	42	112		

[a] Weight and condition determined only from fish collected in November.
[b] Not determined.

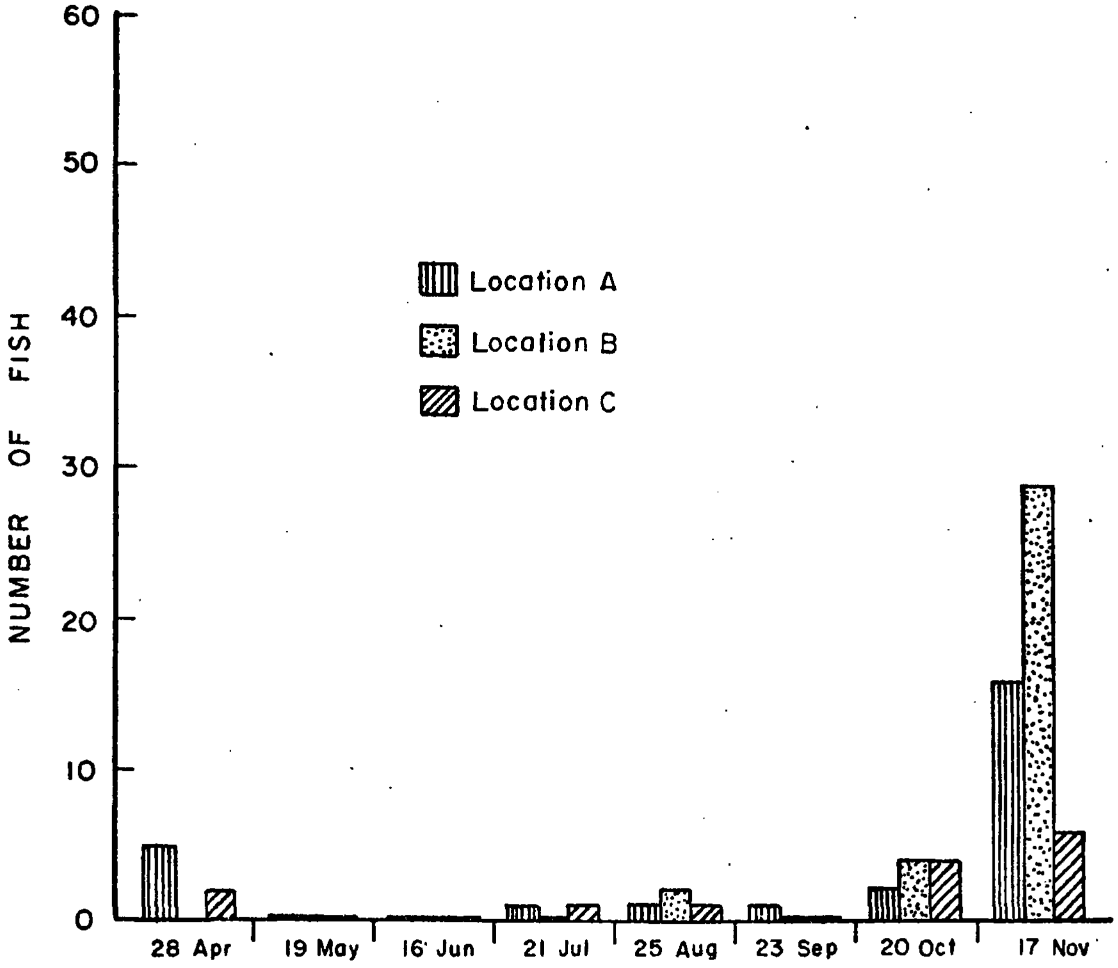

Figure 9.14. Distribution of brown trout collected by gill net in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

As in the case of lake trout, brown trout population in western Lake Michigan are maintained through stocking efforts of state agencies. Large catches of brown trout have been taken in th study area from 1974 through 1976. These increases in brown trout abundance are attributed to attraction to the discharge area during colder months (LaJeone 1976) and to increased stocking efforts by the Wisconsin Department of Natural Resources (1974).

Brown trout ranged in length from 137 to 710 millimeters, but the majority of fish ranged from 370 to 599 millimeters (Table 9.16). Only a small percentage of brown trout stocked annually are marked with fin clips, making age determination difficult. It is also impossible to detect of a fish was stocked or produced naturally. Comparison of sizes in the catch with ages for the few fin clipped fish that have been collected, indicates that age group II and III were most abundant.

Adult brown trout were in ripe gonadal condition in September but no mature fish were collected in October and the few adults taken in November were already spent. There is little evidence that brown trout spawned in the vicinity of KNPP.

Alewife, sculpin and rainbow smelt were the major food items found in brown trout stomachs, and one gizzard shad was also identified (Table 9.11).

j. Chinook salmon

Chinook salmon were collected in large enoungh numbe to be considered one of the major species in the 1976 catch. A tot of 70 was collected, 61 (87.1%) by gill net and 9 (12.9%) by seine

Table 9.16. Length frequency distribution of brown trout collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Size Class (mm)	Number of Fish/Size Class/Month								Total	Mean Weight (g)	Mean Condition (K)
	Month										
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov			
130-139	0	0	0	0	0	0	2	0	2	31.5	1.21
140-149	0	0	0	0	0	0	0	0	0	-	-
150-159	0	0	0	0	0	0	0	0	0	-	-
160-169	0	0	0	0	0	0	0	0	0	-	-
170-179	0	0	0	0	0	0	0	0	0	-	-
180-189	0	0	0	0	0	0	0	0	0	-	-
190-199	0	0	0	0	0	0	0	0	0	-	-
200-209	0	0	0	0	0	0	0	0	0	-	-
210-219	0	0	0	0	0	0	0	0	0	-	-
220-229	0	0	0	0	0	0	0	0	0	-	-
230-239	0	0	0	0	0	0	0	0	0	-	-
240-249	0	0	0	0	0	0	0	0	0	-	-
250-259	0	0	0	0	0	0	0	0	0	-	-
260-269	0	0	0	0	0	0	0	0	0	-	-
270-279	0	0	0	0	0	0	0	0	0	-	-
280-289	0	0	0	0	0	0	0	0	0	-	-
290-299	0	0	0	0	0	0	0	0	0	-	-
300-309	0	0	0	0	0	0	0	0	0	-	-
310-319	0	0	0	0	1	0	0	0	1	395.0	1.26
320-329	0	0	0	0	0	0	0	0	0	-	-
330-339	0	0	0	0	0	0	0	0	0	-	-
340-349	0	0	0	0	0	0	0	0	0	-	-
350-359	0	0	0	0	0	0	0	1	1	660.0	1.47
360-369	0	0	0	0	0	0	0	0	0	-	-
370-379	0	0	0	0	0	0	2	2	4	723.3	1.42
380-389	0	0	0	0	0	0	1	4	5	830.0	1.45
390-399	0	0	0	0	0	0	1	5	6	960.0	1.62
400-409	0	0	0	0	0	0	1	7	8	1032.7	1.57
410-419	1	0	0	0	0	0	1	5	7	1092.0	1.57
420-429	0	0	0	0	0	0	0	6	6	1182.5	1.58
430-439	1	0	0	0	0	0	0	4	5	1206.0	1.47
440-449	0	0	0	0	0	0	0	0	0	-	-
450-459	0	0	0	0	0	0	0	4	4	1386.7	1.47
460-469	0	0	0	0	0	0	2	8	10	1595.0	1.58
470-479	0	0	0	1	0	0	2	0	3	1803.0	1.68
480-489	0	0	0	0	0	0	0	1	1	*a	*
490-499	1	0	0	0	0	0	0	0	1	1650.0	1.40
500-509	0	0	0	0	0	0	0	0	0	-	-
510-519	1	0	0	0	0	0	0	0	1	2150.0	1.57
520-529	0	0	0	0	0	0	0	0	0	-	-
530-539	1	0	0	0	0	0	0	1	2	2200.0	1.48
540-549	0	0	0	1	0	0	0	1	2	2175.0	1.34
550-559	0	0	0	0	0	1	0	1	2	*	*
560-569	0	0	0	0	1	0	0	0	1	3250.0	1.80
570-579	1	0	0	0	0	0	0	0	1	*	*
580-589	0	0	0	0	0	0	0	0	0	-	-

Table 9.16. (continued)

Size Class	Number of Fish/Size Class/Month									Mean	Mean
	Month									Weight	Condition
(mm)	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total	(g)	(K)
590-599	0	0	0	0	0	0	0	1	1	*	*
600-609	1	0	0	0	0	0	0	0	1	*	*
610-619	0	0	0	0	1	0	0	0	1	3500.0	1.54
620-629	0	0	0	0	0	0	0	0	0	-	
630-639	0	0	0	0	0	0	0	0	0	-	
640-649	0	0	0	0	0	0	0	0	0	-	
650-659	0	0	0	0	0	0	0	0	0	-	-
660-669	0	0	0	0	0	0	0	0	0	-	-
670-679	0	0	0	0	0	0	0	0	0	-	-
680-689	0	0	0	0	0	0	0	0	0	-	-
690-699	0	0	0	0	0	0	0	0	0	-	-
700-709	0	0	0	0	0	0	0	0	0	-	-
710-719	0	0	0	0	1	0	0	0	1	6400.0	1.78
Total	7	0	0	2	4	1	12	51	77		

[a] Not determined, fish tagged and released.

(Table 9.3). Chinook salmon comprised 1.3% of the gill net catch and 1.2% of the total catch. June and November were the only months they were not collected and greatest abundance occurred in July and August (Figure 9.2). Chinook salmon were collected by seine only in April and May while they occurred in gill net catches from July through October. Eight of the nine salmon caught by seine were taken at Location 9, but no distributional pattern was apparent for salmon caught by gill nets (Figure 9.15).

The Wisconsin Department of Natural Resources plants large numbers of chinook salmon annually in nearby tributaries and adults return to these streams to spawn. However, natural reproduction in these streams is, at best, extremely limited. No adult chinook salmon were collected within the study area in 1976.

Lengths of chinook salmon ranged from 67 to 445 millimeters with fish ranging from 340 to 445 millimeters comprising the majority of the catch (Table 9.17). All salmon were juveniles and specimens collected in April and May were recently stocked young-of-year. There were no indications of chinook salmon spawning in the vicinity of the Plant.

Results of stomach analyses showed that chinook salmon fed almost exclusively on alewife (Table 9.11).

k. <u>Longnose sucker</u>

Longnose sucker was the least abundant species to contribute substantially to the total catch. Only 57 were collected and all but one were taken by gill net (Table 9.3). They were collected in small numbers from May through October with no

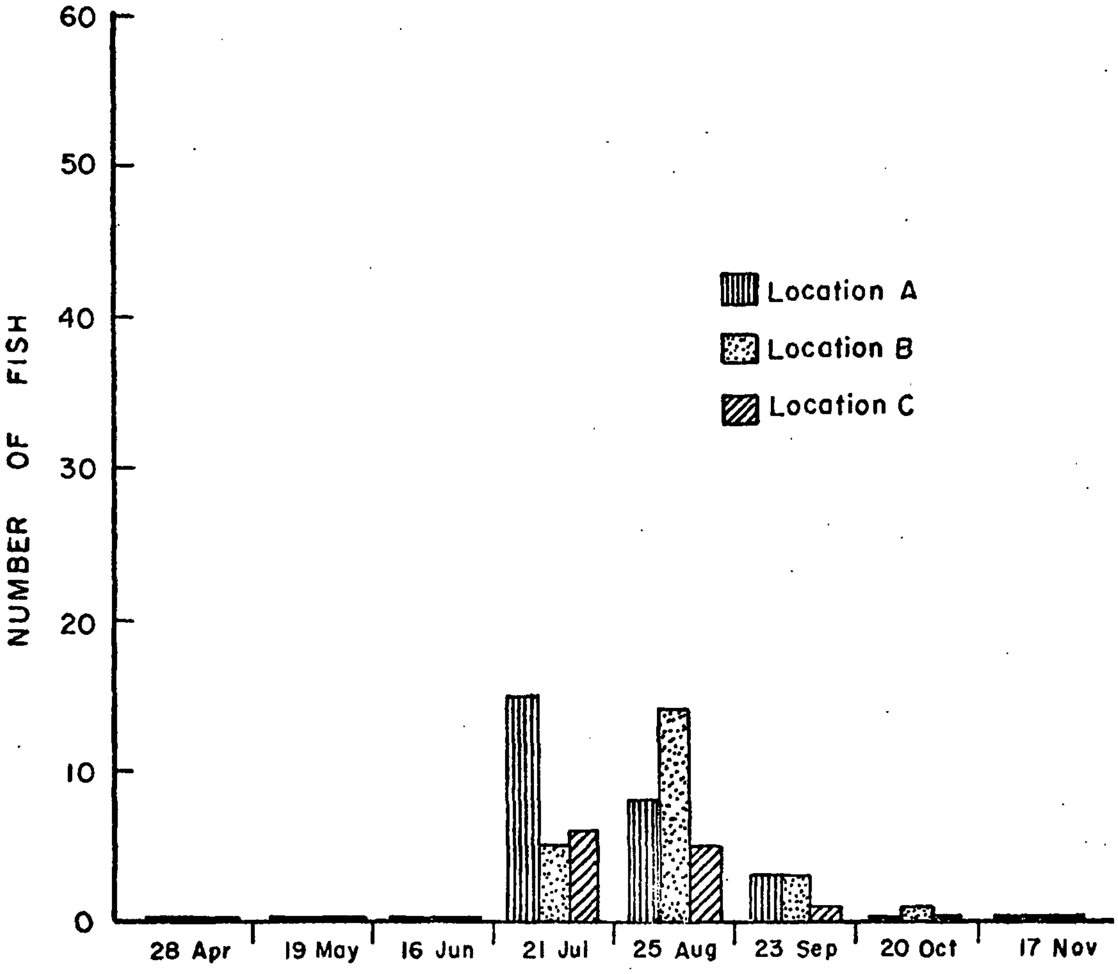

Figure 9.15. Distribution of chinook salmon collected by gill net in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Table 9.17. Length frequency distribution of chinook salmon collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Size Class (mm)	Number of Fish/Size Class/Month								Total	Mean Weight (g)	Mean Condition (K)
	Month										
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov			
60-69	3	0	0	0	0	0	0	0	3	*[a]	*
70-79	2	1	0	0	0	0	0	0	3	*	*
80-89	0	3	0	0	0	0	0	0	3	*	*
90-99	0	0	0	0	0	0	0	0	0	-	-
100-109	0	0	0	0	0	0	0	0	0	-	-
110-119	0	0	0	0	0	0	0	0	0	-	-
120-129	0	0	0	0	0	0	0	0	0	-	-
130-139	0	0	0	0	0	0	0	0	0	-	-
140-149	0	0	0	0	0	0	0	0	0	-	-
150-159	0	0	0	0	0	0	0	0	0	-	-
160-169	0	0	0	0	0	0	0	0	0	-	-
170-179	0	0	0	0	0	0	0	0	0	-	-
180-189	0	0	0	0	0	0	0	0	0	-	-
190-199	0	0	0	0	0	0	0	0	0	-	-
200-209	0	0	0	0	0	0	0	0	0	-	-
210-219	0	0	0	0	0	0	0	0	0	-	-
220-229	0	0	0	0	0	0	0	0	0	-	-
230-239	0	0	0	0	0	0	0	0	0	-	-
240-249	0	0	0	0	0	0	0	0	0	-	-
250-259	0	0	0	0	0	0	0	0	0	-	-
260-269	0	0	0	0	0	0	0	0	0	-	-
270-279	0	0	0	0	0	0	0	0	0	-	-
280-289	0	0	0	0	0	0	0	0	0	-	-
290-299	0	0	0	1	0	0	0	0	1	280.0	1.09
300-309	0	0	0	0	0	0	0	0	0	-	-
310-319	0	0	0	3	0	0	0	0	3	281.7	0.92
320-329	0	0	0	1	0	0	0	0	1	340.0	0.99
330-339	0	0	0	0	0	0	0	0	0	-	-
340-349	0	0	0	0	1	2	0	0	3	353.3	0.87
350-359	0	0	0	3	3	0	0	0	6	430.0	0.97
360-369	0	0	0	3	4	0	0	0	7	482.9	1.02
370-379	0	0	0	1	2	0	0	0	3	496.7	0.94
380-389	0	0	0	4	4	0	0	0	8	544.4	0.96
390-399	0	0	0	1	5	0	0	0	6	584.2	1.10
400-409	0	0	0	3	2	0	0	0	5	653.0	0.99
410-419	0	0	0	3	3	2	0	0	8	677.5	0.96
420-429	0	0	0	2	1	2	1	0	6	733.3	0.97
430-439	0	0	0	1	1	1	0	0	3	833.3	1.03
440-449	0	0	0	0	1	0	0	0	1	880.0	0.99
Total	5	4	0	26	27	7	1	0	70		

[a] Not determined.

particular monthly catch showing peak seasonal abundance (Figure 9.2). Despite the small catch of longnose suckers, there was a pattern to their distribution within the area, as they were most numerous in gill net catches at Location C (Figure 9.16.). Similar catch at Location C have been reported in previous studies (LaJeone 1974, 1975, 1976).

Longnose suckers ranged in length from 165 to 550 millimeters with the majority of fish ranging from 360 to 499 millimete (Table 9.18). No adults in spawning condition were collected and no eggs, larvae or young-of-year were collected. Longnose suckers, like white suckers, undoubtedly utilize nearby tributaries as spawning and nursery areas and do not spawn out in the lake.

1. Miscellaneous species

Valuable sport species uncommonly collected in 1976 included seven rainbow trout, four coho salmon, one brook trout and one hybrid tiger trout (Table 9.3). All four species are maintained through the stocking efforts of the Wisconsin Department of Natural Resources and they may be more abundant in the area than data indicate. Adult rainbow trout and coho salmon were collected in spawnin condition in November but neither species is thought to spawn successfully in the vicinity of the Plant. Results of limited stomach analyses show that rainbow trout fed on alewife and sculpin while coho salmon fed only on alewife (Table 9.11).

Commercially valuable salmonid species collected infrequently in 1976 were seven lake whitefish and five round whitefish, the former being the only species sought commercially in the

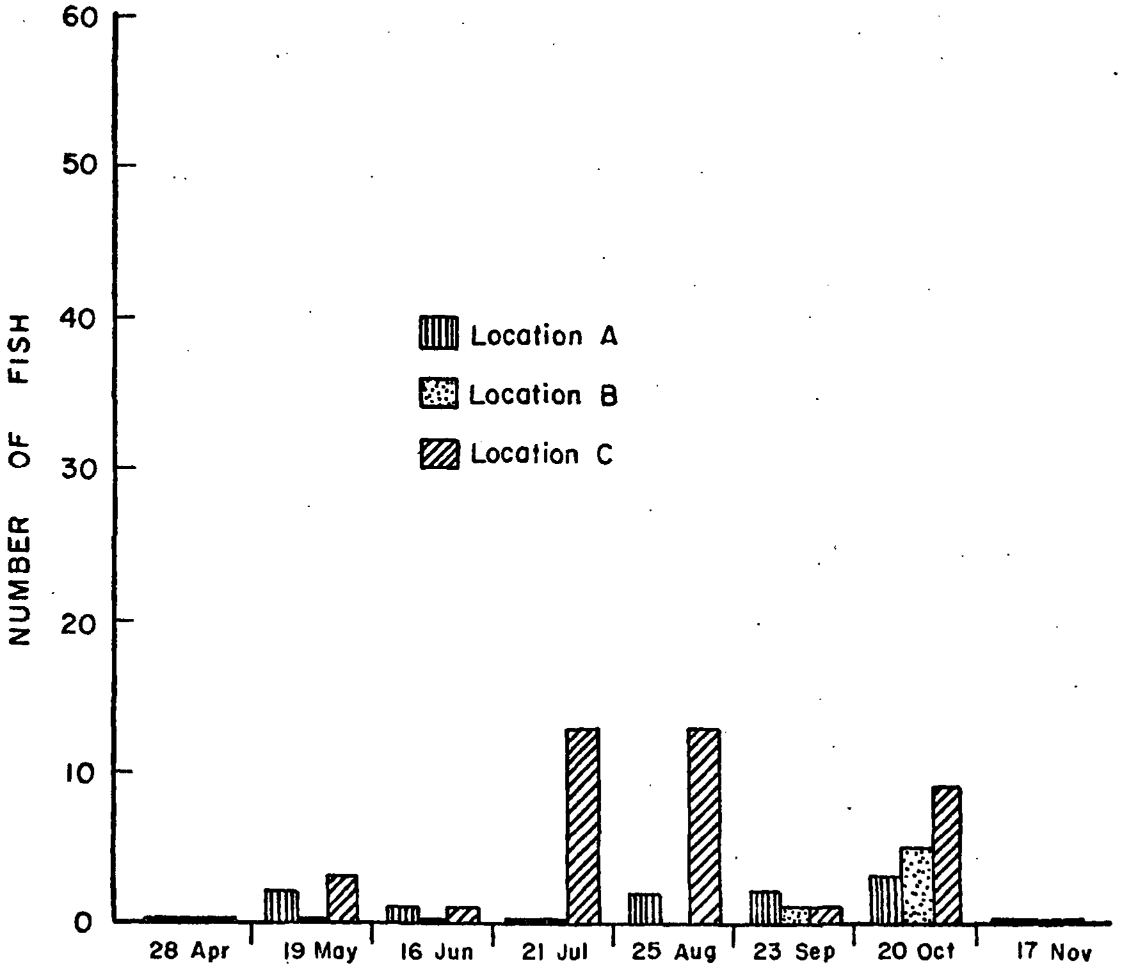

Figure 9.16. Distribution of longnose sucker collected by gill net in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Table 9.18. Length frequency distribution of longnose sucker collected in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

Size Class (mm)	Number of Fish/Size Class/Month									Mean Weight (g)	Mean Condition (K)
	Month										
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total		
160-169	0	0	0	0	0	1	0	0	1	50.0	1.11
170-179	0	0	0	0	0	1	0	0	1	50.0	1.01
180-189	0	0	0	0	0	0	0	0	0	-	-
190-199	0	0	0	0	0	0	0	0	0	-	-
200-209	0	0	0	0	0	0	0	0	0	-	-
210-219	0	0	0	0	0	0	0	0	0	-	-
220-229	0	0	0	0	0	0	0	0	0	-	-
230-239	0	0	0	0	0	0	0	0	0	-	-
240-249	0	0	0	0	0	0	0	0	0	-	-
250-259	0	0	0	0	0	0	0	0	0	-	-
260-269	0	0	0	0	0	0	0	0	0	-	-
270-279	0	0	0	0	0	0	1	0	1	235.0	1.12
280-289	0	0	0	0	0	1	1	0	2	242.5	1.07
290-299	0	1	0	0	0	0	2	0	3	288.3	1.12
300-309	0	0	0	0	0	0	1	0	1	315.0	1.11
310-319	0	0	0	0	0	0	0	0	0	-	-
320-329	0	0	0	0	0	0	0	0	0	-	-
330-339	0	0	0	0	0	0	1	0	1	430.0	1.14
340-349	0	0	0	0	0	0	0	0	0	-	-
350-359	0	0	0	0	0	0	0	0	0	-	-
360-369	0	1	0	0	0	0	1	0	2	555.0	1.16
370-379	0	0	0	0	2	0	2	0	4	577.5	1.12
380-389	0	0	1	0	2	1	0	0	4	663.8	1.17
390-399	0	0	0	0	3	0	1	0	4	695.0	1.15
400-409	0	0	0	2	0	0	0	0	2	715.0	1.09
410-419	0	2	0	4	2	0	1	0	9	758.9	1.07
420-429	0	0	0	1	0	0	2	0	3	773.3	1.02
430-439	0	0	0	0	3	0	1	0	4	780.0	0.97
440-449	0	0	0	1	1	0	1	0	3	850.0	0.98
450-459	0	1	1	0	1	0	0	0	3	856.7	0.92
460-469	0	0	0	1	0	0	1	0	2	1055.0	1.05
470-479	0	0	0	0	0	0	0	0	0	-	-
480-489	0	0	0	2	0	0	0	0	2	1165.0	1.03
490-499	0	0	0	1	1	0	0	0	2	1157.5	0.95
500-509	0	0	0	0	0	0	0	0	0	-	-
510-519	0	1	0	0	0	0	0	0	1	1350.0	
520-529	0	0	0	0	0	0	0	0	0	-	-
530-539	0	0	0	0	0	0	0	0	0	-	-
540-549	0	0	0	1	0	0	0	0	1	1950.0	1.20
550-559	0	0	0	0	0	0	1	0	1	2250.0	1.35
Total	0	6	2	13	15	4	17	0	57		

Wisconsin waters of Lake Michigan. Adults of both species were collected and lake whitefish collected in November were in spent gonadal condition. There is little indication that either species spawns in the vicinity of the Plant.

The remainder of the catch consisted of five creek chubs, two shorthead redhorse, two carp, two fathead minnows, and one ninespine stickleback.

C. Tagging Study

A total of 325 fish was tagged and returned to Lake Michigan in 1976 (Table 9.19). Individuals of five species were tagged but lake trout, brown trout and yellow perch comprised the majority. Twenty-nine tagged fish were recovered in 1976, consisting of 15 lake trout, four brown trout and 10 yellow perch (Table 9.20). Recaptured lake trout consisted of three tagged in 1974, eight tagged in 1975 and four tagged in 1976. Of the four recaptured brown trout, three were tagged in 1975 and one in 1976. Yellow perch recovered this year included three from 1976, one from 1975, five from 1974 and one from 1973.

All but one of the 15 lake trout recaptured were recovered within 30 miles of the point of release (Figure 9.17). The one exception was recaptured approximately 70 miles southeast of the study area off Pentwater, Michigan. Six lake trout traveled north from the Plant area, two of which were taken off Kewaunee, two off Algoma and two off Sturgeon Bay. Seven fish traveled south from the area, two of which were recaptured at the Point Beach Nuclear Plant, four off Two Rivers and one at Pentwater, Michigan. Only

Table 9.19. Summary of fish species tagged and released in Lake Michigan near the Kewaunee Nuclear Power Plant, April through November 1976.

	Number of Fish Tagged/Month								
	Month								
Species	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
Lake trout	13	36	16	9	4	5	146	7	236
Brown trout	3	0	0	0	0	0	0	22	25
Rainbow trout	0	0	0	0	0	0	0	2	2
Lake whitefish	1	0	0	0	0	0	0	0	1
Yellow perch	34	10	0	8	9	0	0	0	61
Total	51	46	16	17	13	5	146	31	325

Table 9.20. Summary of 1976 tag returns from fish tagged in Lake Michigan near the Kewaunee Nuclear Power Plant from 1973 through 1976.

Species	Tagged		Recaptured		Distance Traveled
	Date	Location	Date	Location	
Lake trout	8/28/74	A	8/7/76	Kewaunee, WI.	8 mi, North
Lake trout	9/26/74	A	5/4/76	Sturgeon Bay, WI.	30 mi, North
Lake trout	10/24/74	B	7/21/76	Algoma, Wi.	20 mi, North
Lake trout	4/23/75	B	7/24/76	Two Rivers, WI.	16 mi, South
Lake trout	4/23/75	B	8/21/76	Two Rivers, WI.	16 mi, South
Lake trout	9/24/75	B	7/8/76	Sturgeon Bay, WI.	30 mi, North
Lake trout	9/24/75	A	10/28/76	C	2 1/2 mi, South
Lake trout	10/22/75	C	6/25/76	Pentwater, MI.	70 mi, Southeast
Lake trout	10/22/75	C	7/13/76	Two Rivers, WI.	14 mi, South
Lake trout	10/22/75	A	7/17/76	Kewaunee, WI.	8 mi, North
Lake trout	10/22/75	A	8/31/76	KNPP[a]	1/2 mi, South
Lake trout	4/28/76	C	5/8/76	PBNP[b]	2 1/2 mi, South
Lake trout	4/28/76	A	7/6/76	Two Rivers, WI.	16 mi, South
Lake trout	10/20/76	B	10/31/76	PBNP	4 1/2 mi, South
Lake trout	10/20/76	A	11/2/76	Algoma, Wi.	20 mi, North
Brown trout	11/19/75	A	1/23/76	PBNP	4 1/2 mi, South
Brown trout	11/19/75	B	10/18/76	Sawyer Harbor, Door Cty, WI.	40 mi, North
Brown trout	11/19/75	C	10/25/76	Kewaunee River, WI.	10 mi, North
Brown trout	4/28/76	A	5/8/76	PBNP	4 1/2 mi, South
Yellow perch	8/29/73	C	9/7/76	KNPP	2 mi, North
Yellow perch	7/24/74	C	6/6/76	Kewaunee, WI.	10 mi, North
Yellow perch	7/24/74	C	8/16/76	Kewaunee, WI.	10 mi, North
Yellow perch	8/28/74	A	6/1/76	PBNP	4 1/2 mi, South
Yellow perch	8/28/74	A	9/7/76	KNPP	1/2 mi, South
Yellow perch	9/26/74	C	8/23/76	KNPP	2 mi, North
Yellow perch	8/27/75	B	12/1/76	Two Rivers, WI.	16 mi, South
Yellow perch	4/28/76	B	5/21/76	KNPP	-
Yellow perch	4/28/76	B	6/30/76	Sturgeon Bay, WI.	30 mi, North
Yellow perch	4/28/76	A	8/17/76	KNPP	1/2 mi, South

[a] Kewaunee Nuclear Power Plant.
[b] Point Beach Nuclear Plant.

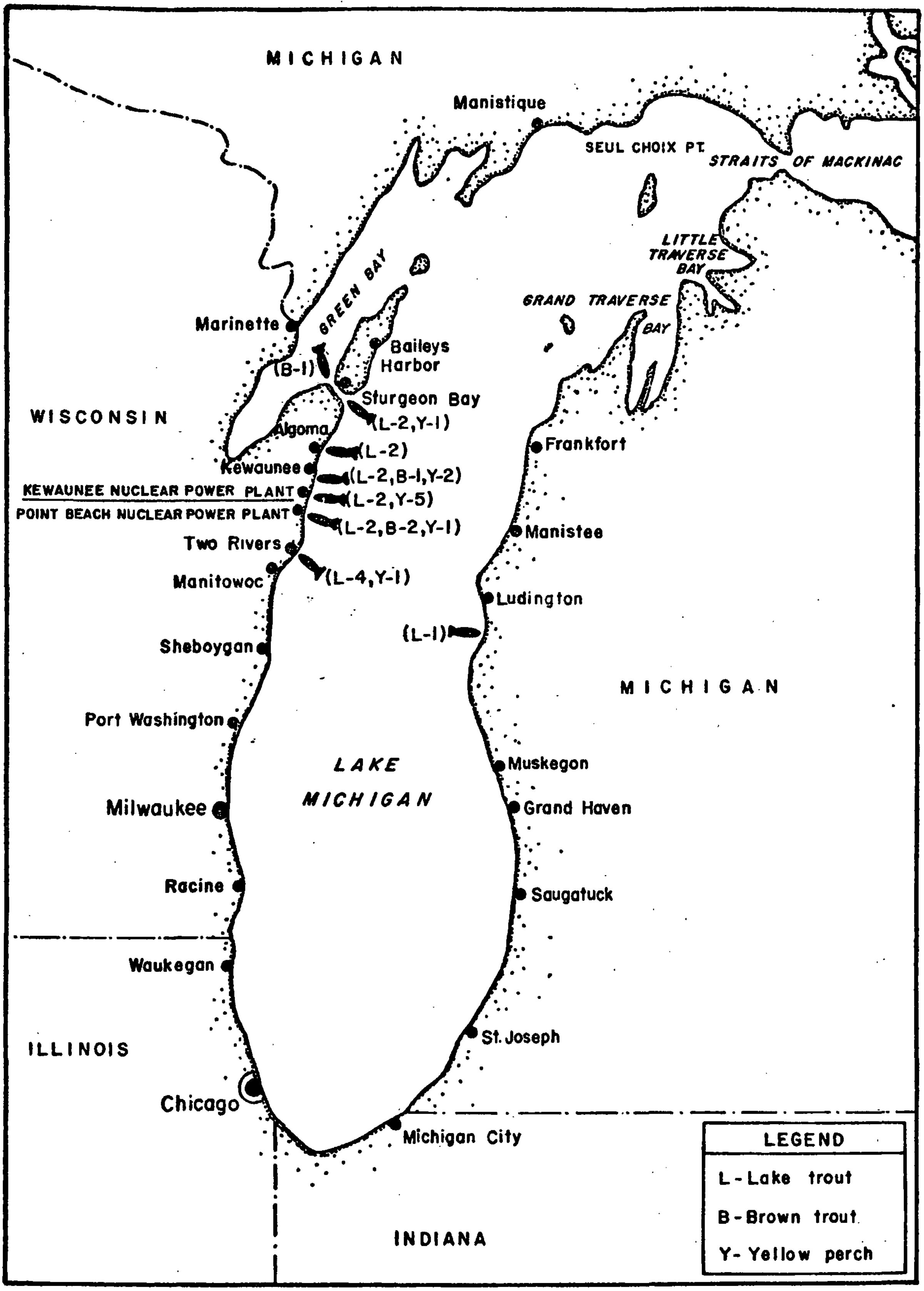

Figure 9.17. Recapture locations and number of fish recaptured in 1976 of fish tagged near the Kewaunee Nuclear Power Plant.

two lake trout were recaptured within the study area, one at the Plant's discharge and the other at Location C. The mean distance traveled by lake trout was approximately 17 miles from the point of release.

Brown trout traveled relatively short distances over short periods of time. Two fish were recaptured nearby at the Point Beach Nuclear Plant discharge, one having been tagged slightly over two months previously and the other only 10 days earlier (Table 9.20). The remaining two fish were recaptured approximately 11 months after tagging. One had traveled about 10 miles north and was caught two miles up the Kewaunee River while the other traveled about 40 miles north to Sawyer Harbor off Green Bay. The mean distance traveld by brown trout was approximately 15 miles from the point of release.

Yellow perch traveled the least of the three species recaptured. The most distant recapture location was for an individual caught off Sturgeon Bay, approximately 30 miles north (Figure 9.17). Three perch traveled north from the study area and two traveled south while five perch were recovered at KNPP (Table 9.20). Two of those recovered at the Plant were found on the intake trash screens while the other three were caught by sport fishermen. One of the perch recovered at KNPP had been tagged three years previously at Location C. The mean distance traveled by yellow perch was only 7.5 miles, a considerable reduction from the 40 mile distance reported in 1975 (LaJeone 1976).

Recapture data from 1976 showed less extensive movements of lake trout and yellow perch than in 1975 but similaritie in brown trout movements were noted. It is felt that these species travel considerable distances during the course of a year but extreme movements about the lake are exceptional. Recapture of several individuals in relatively close proximity to their points of release, even after several years had elapsed since tagging, indicates there may be some pattern to the movements of these species. It appears that none of these species remains in one particular area for extended periods of time, though data do suggust that brown trout will remain in close proximity to thermal effluents during the colder months. There were no indications that normal seasonal migrations of species inhabiting the study area have been altered by Plant operation.

D. Comparison of Catch Data from 1973 through 1976

Catch data from studies conducted from 1973 through 1976 are comparable as the programs for each study were identical except for minor variations in the dates of collections. The 1973 study covers the preoperational phase of KNPP while the 1975 and 1976 studies monitored operational conditions. The 1974 study encompassed preoperational and operational monitoring as KNPP began commercial operation in June 1974.

A summary of catch data for all four years is presented in Table 9.21. A total of 30 species and one hybrid has been collected over the four year period; 24 species in 1973, 22 species in 1974, 23 species in 1975, and 21 species plus one hybrid in 1976. Differences in species composition between respective studies were

Table 9.21. Comparison of catch totals for fish species collected in Lake Michigan near the Kewaunee Nuclear Power Plant from 1973 through 1976.

	1976				1975				1974				1973			
	Sampling Locations				Sampling Locations				Sampling Locations				Sampling Locations			
Species	A/5[a]	B/9	C/19	Total	A/5	B/9	C/19	Total	A/5	B/9	C/19	Total	A/5	B/9	C/19	Total
Alewife	716	734	1222	2672	2167	1405	70935	74507	2305	1177	2881	6363	1175	654	977	2806
Rainbow smelt	466	198	478	1142	38	53	25	117	198	354	451	1003	172	70	114	356
Lake chub	781	37	77	895	144	55	50	249	180	126	66	372	149	115	72	336
Lake trout	136	122	174	432	199	186	185	570	153	157	138	448	109	141	106	356
Yellow perch	59	29	79	167	60	155	63	278	118	115	140	373	293	303	113	709
White sucker	86	20	57	163	49	29	61	139	33	22	88	143	90	126	57	273
Longnose dace	50	5	73	128	14	45	133	192	126	11	47	184	80	33	31	144
Slimy sculpin	76	0	36	112	11	8	10	29	10	4	11	25	80	142	65	287
Brown trout	26	35	16	77	58	44	14	116	57	42	15	114	7	1	3	11
Chinook salmon	27	31	12	70	1	0	0	1	6	10	6	22	4	0	6	10
Longnose sucker	10	7	40	57	9	7	91	107	14	6	78	98	13	12	45	70
Rainbow trout	1	4	2	7	0	1	1	2	5	3	9	17	1	2	5	8
Lake whitefish	3	1	3	7	2	0	0	2	13	20	8	41	3	2	7	12
Round whitefish	0	4	1	5	5	2	2	9	0	0	3	3	0	1	0	1
Creek chub	5	0	0	5	0	0	1	1	0	1	0	1	0	0	0	0
Coho salmon	2	2	0	4	0	1	0	1	22	12	11	45	12	9	4	25
Shorthead redhorse	2	0	0	2	0	0	0	0	0	0	0	0	0	1	0	1
Carp	1	0	1	2	0	1	1	2	0	5	3	8	1	1	0	2
Fathead minnow	1	0	1	2	2	0	0	2	0	0	0	0	1	0	1	2
Brook trout	0	1	0	1	2	0	0	2	3	2	5	10	0	0	0	0
Tiger trout	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Ninespine stickleback	1	0	0	1	0	0	0	0	0	1	0	1	1	1	0	2
Cisco	0	0	0	0	2	4	0	6	0	0	0	0	0	0	0	0
Bloater	0	0	0	0	0	0	0	0	1	1	0	2	0	0	1	1
Burbot	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Gizzard shad	0	0	0	0	0	0	1	1	0	0	0	0	2	0	7	9
Golden shiner	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
Common shiner	0	0	0	0	0	0	2	2	2	0	0	2	0	0	0	0
Spottail shiner	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3
Black bullhead	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2
Mottled sculpin	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Total	2449	1231	2272	5952	2764	1996	71577	76337	3240	2069	3961	9276	2198	1615	1614	5427
% of Annual Catch	41.4.	20.7	38.2	100.0	3.6	2.6	93.8	100.0	35.0	22.3	42.7	100.0	40.5	29.8	29.7	100.0

[a] Gill net location/corresponding minnow seine location.

restricted to minor species infrequently collected in all four years

Total catches varied appreciably between years but fluctuations in total numbers of fish collected were largely attributed to the relative abundance of alewives (Table 9.21). Alewives comprise the majority of the catch each year and dramatic fluctuations in alewife catches from one year to the next are reflected as similar fluctuations in the total catches.

Fluctuations in annual catches of other major species also occurred from year to year. Dramatic variations in rainbow smelt catches occurred each year with 1973 and 1975 catches extremel small compared to 1974 and 1976 catches (Table 9.21). Lake chubs were more than three times as numerous in 1976 than in 1975. Almost four times as many slimy sculpins were collected in 1976 than in 1974 and 1975 but the 1973 catch was 2 1/2 times greater than the 1976 catch. Brown trout were only occasionally taken in 1973 but have become a major constituent of the total catch in the last three years, and more chinook salmon were caught in 1976 than in all three previous years combined. Catches of lake trout, white sucker and longnose dace were much less variable. Yellow perch have undergone a steady decline each year and longnose suckers, which were steadily increasing each year, declined sharply from the 1975 catch.

Most of these fluctuations in annual catches, with the exception of brown trout and yellow perch, are viewed merely as sampling anomalies. Increased brown trout abundance is believed to be the result of increased stocking rates and attraction to the discharge area. The decline in yellow perch abundance is attributed to poor recruitment from younger age groups. There are no other indications that KNPP operation has affected the species composition or relative abundance of fishes in the vicinity of the Plant.

Comparisons were also made to determine if changes in seasonal abundance or spatial distribution of fish have occurred which may be attributed to Plant operation. Peak seasonal abundance for several major species was similar over the four year period (Figure 9.2; LaJeone 1974, 1975, 1976). Adult alewives reached peak abundance in May 1973, June 1974 and 1975, and May and July 1976. Rainbow smelt were most abundant in April of all four years, and the largest catches of lake trout occurred in September and October all four years. Lake chubs were collected in substantial numbers in most months of 1973, but peak abundance occurred in June from 1974 through 1976. Brown trout were most numerous in September and November 1974 and were abundant only in November 1975 and 1976. Peak abundance of slimy sculpin occurred in May 1973 and 1976. Distinct patterns of seasonal abundance were not apparent for yellow perch, white suckers, longnose suckers and longnose dace.

Few patterns of spatial distribution were detected for major species within the study area and, with the exception of brown trout and carp, there have been no apparent changes in fish distribution within the area directly related to Plant operation. Recapture data on brown trout and comparison of November 1976 catch data with water temperatures indicate that brown trout were attracted to the Plant's discharge and that they may remain in close proximity to thermal effluents during the colder months. Carp were observed swimming in the immediate discharge area in 1974 and 1975 (LaJeone 1975 and 1976); however, similar observations were not made in 1976, though they undoubtedly still occur there. That certain species of fish concentrate in the vicinity of thermal discharges at various times of year (Romberg et al 1975) is not disputed, but no evidence of increased densities of fish near the KNPP discharge has been detected other than for brown trout and carp.

The scarcity of lake chubs, longnose dace and slimy sculpin at Location 9 in 1976 is not a direct result of KNPP operation. These species apparently prefer rock and gravel substrates to fine sand. The substrate at Location 9 has been considerably sandier than those at Locations 5 and 19 in previous studies, but it appears to have become even sandier in 1976. Consequently, these species did not occur as commonly at Location 9 as in areas of more suitable habitat.

IV. Summary and Conclusions

1. No appreciable thermal influence of the discharge on fish sampling locations closest to the Kewaunee Nuclear Power Plant (Locations B and 9) was detected. Increased water temperatures possibly due to the Plant's discharge were detected only on 17 November at Locations A and B.

2. Twenty-one species of fish and one hybrid were collected in Lake Michigan near the Plant in 1976, comprising a total catch of 5952 fish. Gill nets captured 4789 (80.5%) fish and shoreline seining accounted for 1163 (19.5%) fish.

3. Principal species collected within the study area were alewife, rainbow smelt, lake chub, lake trout, yellow perch, white sucker, longnose dace, slimy sculpin, brown trout, chinook salmon and longnose sucker. Additional species of sport or commercial value collected in the area were rainbow trout, coho salmon, brook trout, tiger trout, lake whitefish and round whitefish.

4. Seasonal abundance and spatial distribution were plotted for major species. Peak abundance of alewife, smelt, lake chub and lake trout in the study area appeared to coincide with spawning seasons while peak abundance of other major species did not coincide. With the exception of longnose sucker, no distinct patterns of spatial distribution within the study area were detected for principal species. However, intermittent tributaries and different habitats at seining locations did influence the distribution of some species.

5. Species collected in spawning condition within the area were alewife, smelt, lake chub, lake trout, rainbow trout, coho

salmon, and yellow perch. Species believed to have spawned successfully in the vicinity of KNPP were alewife, smelt, lake chub, longnose dace and slimy sculpin.

6. Principal forage of larger, predatory species inhabiting the area consisted of alewife, smelt and slimy sculpin.

7. Data gathered from the recovery of tagged fish indicate that lake trout, brown trout and yellow perch travel considerable distances along the western shore of Lake Michigan, though extreme movements are exceptional. Recapture of several fish in close proximity to the point of release further indicates that there may be some pattern in their seasonal movements. Brown trout apparently remain in the vicinity of thermal effluents for some time during the colder months.

8. Comparison of data compiled over the last four years fail to depict any substantive changes in the fish population of the are attributable to Plant operation. Considerable variations in specie composition, annual catches, seasonal abundance and spatial distribution of the fish community could not be related to operation of the Plant. Seasonal attraction of brown trout and carp to the discharge area were the only effects of Plant operations observed.

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NALCO ENVIRONMENTAL SCIENCES

Chapter 10

SHORELINE EROSION

B. G. Johnson

OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM
OF LAKE MICHIGAN NEAR
KEWAUNEE NUCLEAR POWER PLANT

SIXTH ANNUAL REPORT
January - December 1976

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Chapter 10

SHORELINE EROSION

B. G. Johnson

I. Introduction

One of the physical conditions to be documented and described in the vicinity of the Kewaunee Nuclear Power Plant (KNPP) is shoreline erosion. This commitment was made by the Wisconsin Public Service Corporation in the KNPP Environmental Technical Specifications, Appendix B. The documentation for this study was accomplished by means of low-level aerial photographs taken during 1976, the third year of Plant operation and the sixth year of environmental monitoring studies.

The primary objectives for conducting this program in 1976, were:

1. to determine the present state of shoreline erosion;
2. to describe the seasonal variation in the relative degree of erosion occurring;
3. to continue documentation of erosion during the operational period for comparison with data collected since the beginning of Plant operation and during the pre-operational period in the vicinity of the KNPP; and
4. to fulfill the requirements of the Environmental Technical Specifications, Appendix B. Section 4.0 Environmental Surveillance and Special Studies, as approved by the U.S. Nuclear Regulatory Commission.

II. Field and Analytical Procedures

Aerial photographs of the shoreline in the vicinity of the KNPP were taken during the first two quarters of 1976, from a point approximately 2 1/4 miles north of the Plant to a point approximately 2 1/2 miles south of the Plant, to determine the extent of shoreline erosions or deposition. The two quarterly photographic dates were 23 March and 2 July 1976.

Photographs were taken from a Cessna 172 Skyhawk II rented from Green Bay Aviation, Austin Straubel Field, Green Bay, Wisconsin This high-wing aircraft was an excellent vehical from which to take low-altitude photographs because of its window configuration and maneuverability. During each photographic trip, photographs were taken from at least three altitudes and while flying either parallel to the shoreline or perpendicular to it. Altitudes were usually at 150-200 ft and at 250-300 ft while flying parallel to the shoreline and just offshore. This permitted close-up photos and observations to be made of the beach and bluff zones. Photographs were keyed to the same topographic features or landmarks during each quarter for comparative purposes. Photos taken perpendicular to the shoreline were taken from an altitude of 250-300 ft while crossing back and forth over the shoreline permitting photos and observations to be made up and down the shoreline. In addition, higher altitude photographs, from approximately 1000 ft, were taken of the KNPP and immediate shoreline both north and south of the Plant.

In 1976, aerial photographs were taken on a quarterly basis during the first half of the year, completing the full second year of Plant operation. Aerial photographs of the shoreline have been taken previously during the preoperational period in 1971, 1972, and 1973, and during the first and second year of operation in 1974, and 1975 (Industrial BIO-TEST Laboratories, Inc. 1972, 1973, 1974, 1975; NALCO Environmental Sciences 1976).

Records of water levels in Lake Michigan were obtained from the U.S. Department of Commerce (Department of Commerce 1977a, 1977b). Water levels served as a basis for making seasonal comparisons. Meteorological conditions existing at the time of aerial photography were based on observations made in the vicinity of the KNPP, supplemented by meteorological data from Austin Straubel Field, Green Bay.

III. Results and Discussion

The present Lake Michigan shoreline in the vicinity of the Kewaunee Nuclear Power Plant is characterized by a narrow beach composed of beach sand and gravel, which grades to gravel and rubble out from shore (Poff and Threinen 1966), backed by steep, unstabilized soil banks or bluffs ranging from 10 to 60 ft in height. Grass and tree cover on the face of the bluffs is uncommon except in some areas north of the Plant. Trees are common in ravines associated with the small tributaries entering Lake Michigan within the study area and this accounts for the occasional presence of fallen trees along the shoreline.

These facts are confirmed by the photographic record that was made during 1976 which also documents the present state of erosion in the vicinity of the KNPP. Some typical, oblique view photographs are presented in Figures 10.1, 10.2, 10.3 and 10.4, documenting typical shoreline conditions at specific locations both north and south of the Plant and in the vicinity of the discharge. Figure 10.5 and 10.6 present photographs taken along the shoreline immediately north and south of the Plant. Finally, higher altitude photographs of the immediate KNPP shore-line area permit an overview of the general area near the Plant (Figure 10.7).

The shoreline in the vicinity of the KNPP continues to show evidence of past severe erosion, principally due to continued high water levels in Lake Michigan. Shore erosion is related to lake levels in Lake Michigan, and a significant correlation has been noted between the average rate of erosion and the average

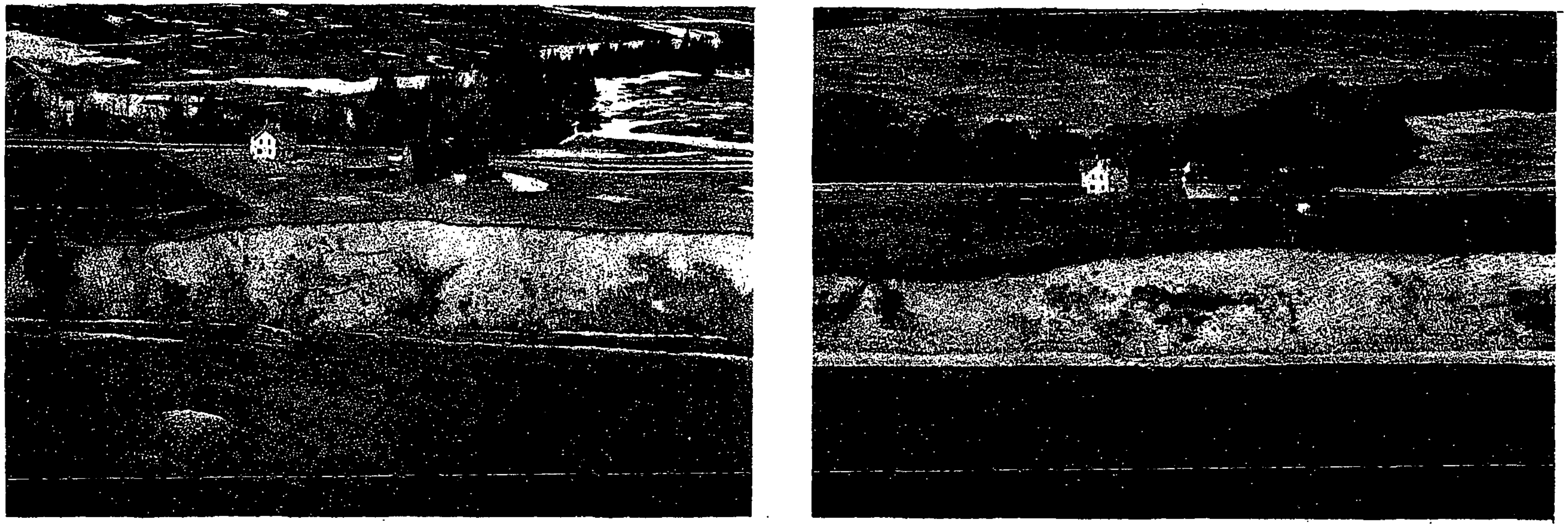

Figure 10.1. Shoreline approximately 1 mi north of the KNPP showing steep, unstabilized soil banks, 1976. (Left, March 23; Right, July 2)

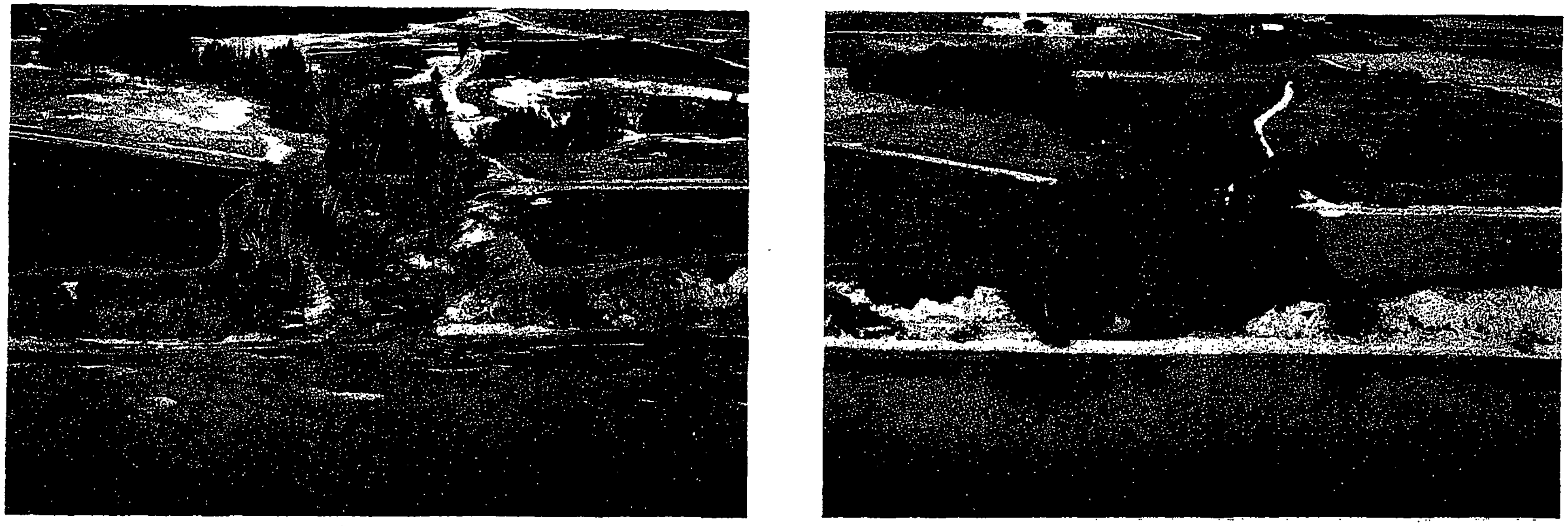

Figure 10.2. Seasonal erosion and deposition at mouth of creek located 3/4 mi north of the KNPP, 1976. (Left, March 23; Right, July 2)

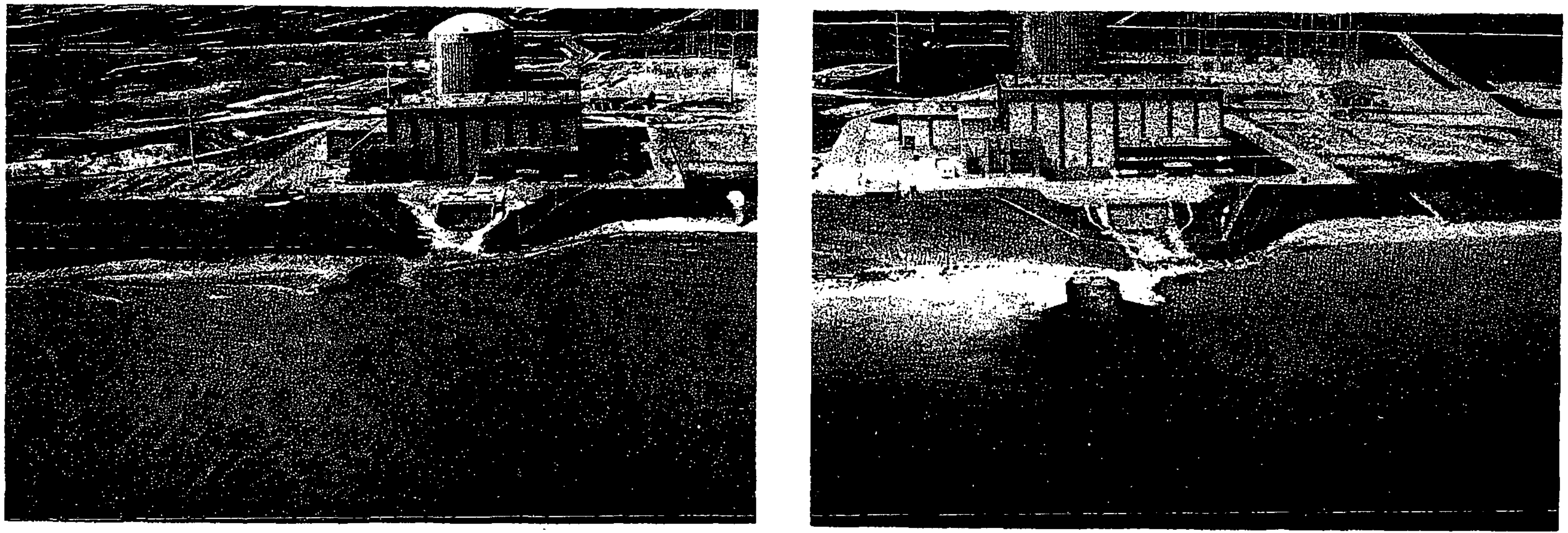

Figure 10.3. Shoreline and lake levels at the KNPP in the immediate vicinity of the discharge, 1976. (Left, March 23; Right, July 2)

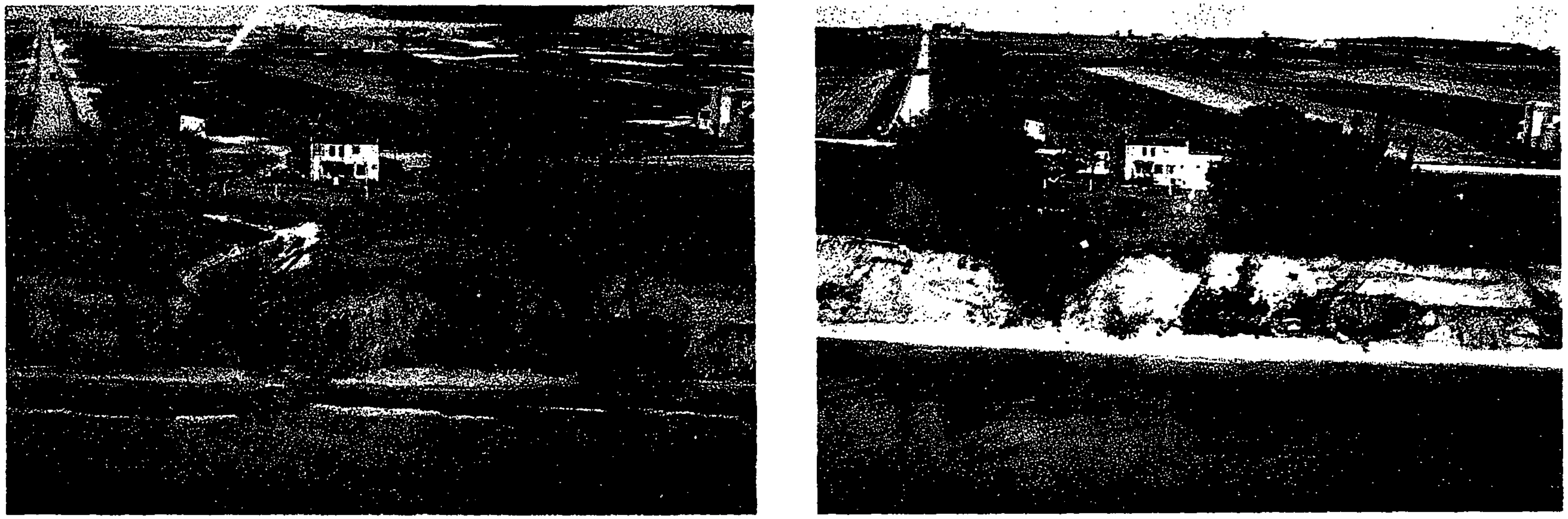

Figure 10.4. Shoreline approximately 1 mi south of the KNPP, 1976. (Left, March 23; Right, July 2)

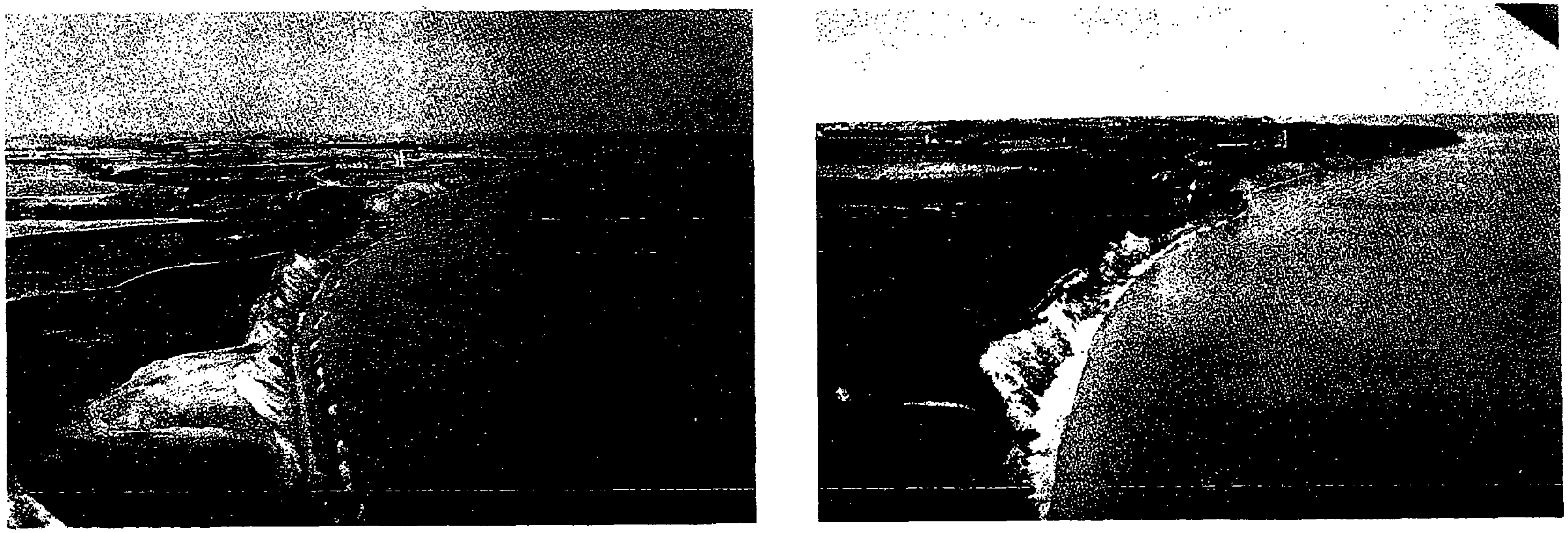

Figure 10.5. Configuration along the shoreline immediately to the north of the KNPP, 1976. (Left March 23; Right, July 2)

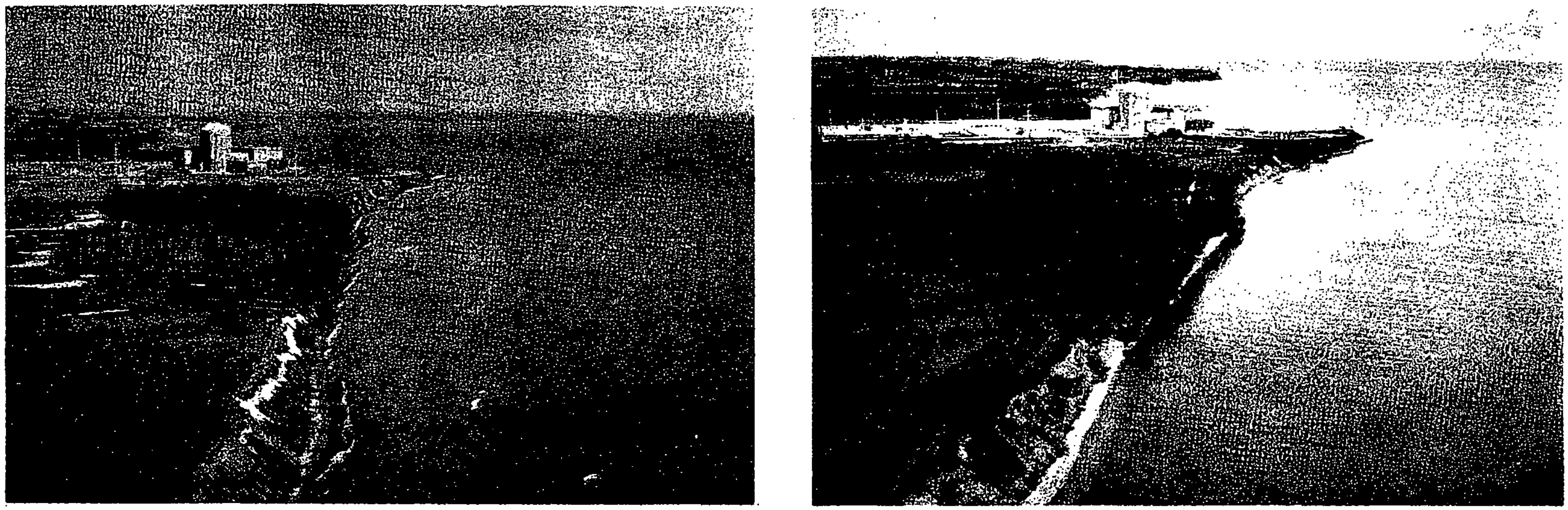

Figure 10.6. Configuration along the shoreline immediately to the south of the KNPP, 1976. (Left, March 23; Right, July 2)

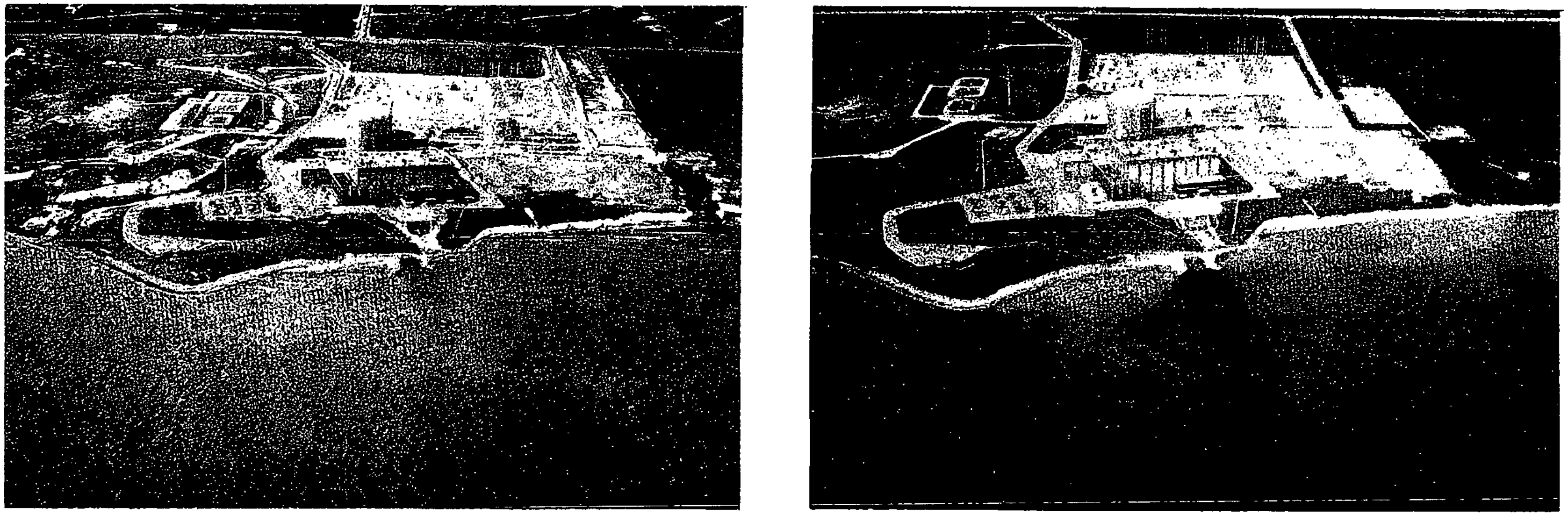

Figure 10.7. Higher altitude photographs showing general shoreline configuration in the vicinity of the KNPP, 1976. (Left, March 23; Right, July 2)

lake levels for periods of measurement (Seibel 1974). Lake Michiga water levels during 1976, for the period when aerial photographs and observations were made, are shown in Table 10.1. The Milwaukee and Sturgeon Bay Canal locations permit an accurate estimate of lake levels in the vicinity of the KNPP as these are the closest official lake gauging stations both north and south of the Plant. Water levels were nearly identical with those for the same periods in 1975, indicating continuing high water levels in 1976 and simila seasonal fluctuations. Seasonal differences in beach exposure and lake levels are apparent from photographs taken in the vicinity of the KNPP (Figures 10.1 through 10.7). The forecast that average fall and winter weather would yield lower levels on all of the Grea Lakes by March 1976 (IAGLR 1975) was not reflected in the lake-leve data for the first half of 1976.

Meteorological conditions during 1976, for the periods when aerial photographs and observations were made, are shown in Table 10.2. These data are provided to assist further in understanding the various factors affecting wave action and apparent water levels. For example, on 23 March with the surface winds relatively strong and steady out of the southwest (20 to 25 mph), the water level appeared to be higher than that actually recorded (Table 10.1) due to the higher waves from the southeast and greater wave run-up on the beaches.

The shoreline in the vicinity of the KNPP has been subjected to severe erosion during the past several years. Berg and Collinson (1976) reported that bluff erosion from wave attack

Table 10.1. Lake Michigan water levels during 1976.[a]

Photographic Date and Location	Daily Mean	Monthly Mean	Daily Maximum	Daily Minimum
March 23				
Milwaukee[b]	579.56	579.77	580.67	578.82
Sturgeon Bay[c]	579.71	579.73	580.52	579.10
July 2				
Milwaukee	580.65	580.61	581.04	580.20
Sturgeon Bay	580.62	580.55	580.91	580.22

[a] Elevations are in feet above mean water level in Gulf of St. Lawrence at Father Point, Quebec, the International Great Lakes Datum (IGLD).

[b] Based on levels determined at Milwaukee, Wisconsin, Station Number 7057 (Department of Commerce 1977a).

[c] Based on levels determined at Sturgeon Bay Canal, Wisconsin, Station Number 7072 (Department of Commerce 1977b).

Table 10.2. Meteorological conditions in the vicinity of the KNPP at the time of aerial photography, 1976.[a]

Date	Direction	Wind Speed (mph)	Cloud Cover
March 23	SW	20 to 25	Clear
July 2	Calm to NE	3 to 5	High thin overcast

[a] Observations taken at the time of the photographic flight, supplemented by meteorological data from Austin Straubel Field, Green Bay, Wisconsin.

becomes significant when lake levels rise above 579 ft IGLD (International Great Lakes Datum). Based on actual lake levels measured during the period of study in 1976 (Table 10.1) and those reported in 1975 and earlier, it is apparent that high water levels and wave attack were the major contributors to the erosion observed in the vicinity of the KNPP. Davis et al. (1974) reported that most extensive losses are in the fall, and a less damaging period of erosions occurs after ice breaks up in the spring. During 1976, observations indicated that only minor erosion occured during the first and second quarters. Because of the absence of severe spring storms in 1976, there were no significant changes in shoreline configuration between January and June. The minor earth slides noted reflected primarily the natural, bank stabilizing processes.

Toward the end of the year 1976, reported water levels (U.S. Department of Commerce 1977a and 1977b) were lower than any that have been observed during the last several years. While this may seem to indicate the possible end to the severe erosion cycle of the early 1970's, Berg and Collinson (1976) suggested that bluff erosion does not always decrease as lake levels decrease. A lag commonly occurs wherein the rate of bluff recession is maintained or even accelerated, mainly because of the time required to revegetate and stabilize denuded bluffs. On this basis, the degree of erosions observed over the past several years will very likely continue into the immediate future near the KNPP, even if lake water levels were to recede.

There was no unusual or unexpected shoreline erosion or deposition of sediments observed in the vicinity of the KNPP that could be attributed to the operation of the Plant in 1976. A comparison of 1976 data with data collected since the beginning of Plant operation and during the pre-operational period indicates that the presence of the KNPP on the Lake Michigan shoreline has had an insignificant effect on local erosion.

IV. Summary and Conclusions

1. The shoreline in the vicinity of the KNPP continues to be subjected to severe erosion and much of it continues in an unstabilized state. The principal cause appears to be continued high lake levels (above 579 ft,IGLD) and wave attack associated with storms and high winds.

2. Considerable differences in local rates of erosion are apparent within the stretch of shoreline where observations were made during this study.

3. No major changes were observed in shoreline configuration in 1976; minor earth slides reflected natural bank stabilizing processes.

4. No unusual or unexpected erosion was noted that could be attributed to the operation of the KNPP, either at the present time or by comparison with operational photographs taken earlier and with those taken during the preoperational period.

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